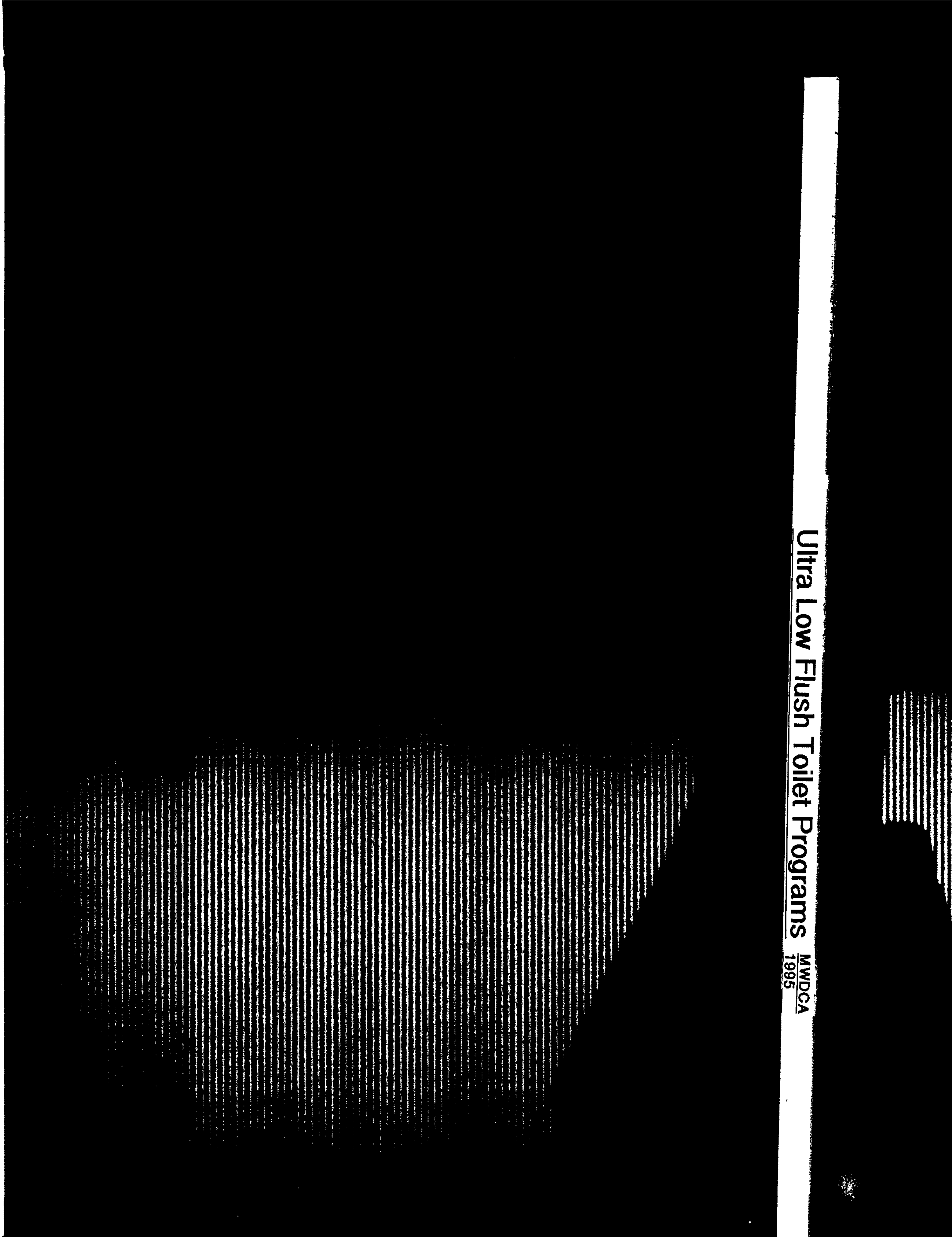
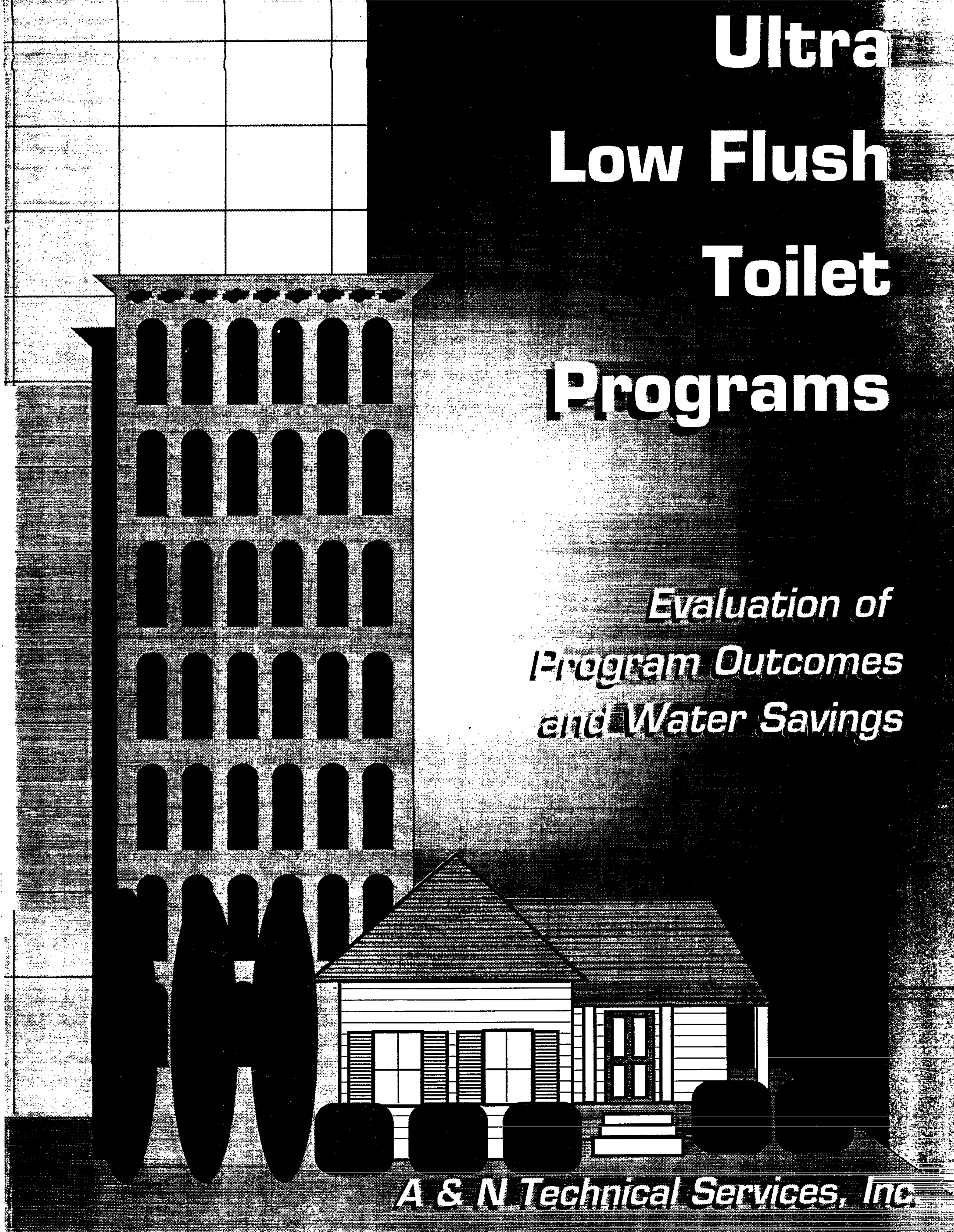


Ultra Low Flush Toilet Programs

MWDCA
1995

Ultra Low Flush Toilet Programs

Evaluation of Program Outcomes and Water Savings



A & N Technical Services, Inc.

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ULTRA LOW FLUSH TOILET PROGRAMS: EVALUATION OF PROGRAM OUTCOMES AND WATER SAVINGS

July 1995

A Report Submitted to

The Metropolitan Water District of Southern California
350 South Grand Avenue
Los Angeles, CA 90071

By

Thomas W. Chesnutt

Casey N. McSpadden

Anil Bamezai

A&N Technical Services, Inc.

1460 Fourth Street, Suite 307 • Santa Monica, CA 90401-2329 • Tel: 310-458-7266 • Fax: 310-458-7261
1030 15th Street, NW, Suite 905 • Washington, DC 20005-1503 • Tel: 202-789-4070 • Fax: 202-789-4074

PREFACE

The Metropolitan Water District of Southern California has been supporting programs, implemented by its member agencies, to encourage the installation of high-efficiency "Ultra Low Flush" (ULF) toilets. Many of these programs offer a cash rebate for customers who install ULF toilets. Though first targeted at residential customers, these rebate programs have been expanded to commercial and industrial customers. More than seven hundred and fifty thousand toilets have been installed in the first four years of toilet rebate programs in the Metropolitan Water District service area.

Urban water suppliers that are signatories to the Memorandum of Understanding (MOU) Regarding Urban Water Conservation in California are required to implement ULF toilet "retrofit" programs in accordance with Best Management Practice 16 (BMP 16). Based on evidence from water savings by the first year participants in ULF toilet rebate programs in Los Angeles and Santa Monica, the California Urban Water Conservation Council adopted Exhibit 6 "Assumptions and Methodology for Determining Estimates of Reliable Savings from the Installation of ULF Toilets," on July 30, 1992. Exhibit 6 provides a methodology for calculating the level of effort required by BMP 16 for the residential sector. The Council elected to defer consideration of similar estimates for the commercial and industrial component of BMP 16 until additional studies could be conducted.

To assist water planners in reliably accounting for water savings achieved through ULF toilet rebate programs, this report details the continuing impact evaluation that produced Exhibit 6. Questions arose in the initial impact evaluation as to the persistence of water savings and the applicability to the commercial and industrial sectors. This report provides results based upon a continuation of initial impact evaluation. These results should interest all signatories of the MOU as well as other utilities that count on demand-side management to yield a portion of their future water supply.

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EXECUTIVE SUMMARY

Net water savings achieved by ultra low flush (ULF) toilet rebate programs in Los Angeles and Santa Monica were estimated using statistical models of billed household water use. Because these programs occurred during an ongoing drought emergency, the amount of water savings attributable solely to these rebate programs was measured by analyzing the amount of additional water saved by participating households compared to nonparticipating households, controlling for household characteristics and climatic variation. This continuing impact evaluation also presents evidence from new types of targeted toilet replacement sites: 1) several hundred commercial toilet replacement sites in Los Angeles, 2) a public school toilet and urinal replacement program in Santa Monica, and 3) an innovative replacement program run by a community-based organization in East Los Angeles.

Persistence of Water Savings

The first impact evaluation of ULF toilet rebate programs examined water use early in the drought emergency (mid-1990 to early 1991) when calls for voluntary reduction in water use were in effect. First year participants were estimated to save 35 to 40 gallons per dwelling per day. As the drought continued, mandatory cutbacks were instituted. Did the increase in the level of ongoing conservation decrease the net effect of toilet rebate programs? Table 1 suggests that the water savings per participating household did reach or exceed the levels experienced in the first year of ULF toilet retrofit programs.

Table 1 Estimated Net Savings per Dwelling in Gallons per Dwelling per Day (Uncertainty range in parentheses)

Single Family Households	41.2 (38.4 - 44.0)
Multiple Family Units	44.0 (42.7 - 45.2)

Though the level of ongoing conservation greatly increased during the second year of ULF toilet rebates, the level of water savings per household remained fairly stable. Does this mean that the cost-effectiveness of the programs remained constant? Not if the number of ULF toilets replaced in each household changed. As the ULF rebate programs continued, second year participants tended to perform a more complete replacement of toilets in the household: the mean number of replaced toilets per household went up from 1.3 to 1.5 toilets per single family household and from .7 to 1 toilet per multiple family unit. Thus, a greater number of ULF toilets were used to achieve the levels of water savings per household provided by Table 1. How much water did each toilet save?

Arriving at an estimate of the savings per ULF toilet requires more than dividing Table 1 by the mean number of installed toilets per household. The net household savings in Table 1 also reflect installation of low-flow showerheads when they were not already present. Table 2 provides the estimated savings per device derived from a statistical model that explains per household conservation by the number of toilets and showerheads replaced.

Table 2 Estimated Net Savings per ULF Toilet or Low-Flow Showerhead in Gallons per Device per Day

	Savings per ULF Toilet	**Savings per LF Showerhead**
Single Family Household	21.6	5.5
Multiple Family Unit	40.3	5.2

It appears that the increased penetration rate of toilets within a household drove down the per toilet water savings. This accords with the finding that the first toilet installed in a home saves more water than the second. This finding from the first impact evaluation continues to hold up in this evaluation. Table 3 displays the estimated per toilet savings by the number of ULF toilets replaced.

Table 3 Mean Savings per Toilet By Number of ULF Toilets Replaced

	Mean Savings per ULF Replaced Number of ULFs Replaced per Dwelling 1 ULF	 2 ULFs	 3 ULFs	
Single Family	30	21	19	Gallons per Day per ULF Toilet
Multiple Family	44	34	—	

Savings in the Commercial Sector

Based on a relatively small sample of less than three hundred participating commercial sites, we estimate a mean savings of 73.6 ± 3 gallons per ULF toilet replaced. Several cautionary notes should be made. First, there is no such thing as an "average" commercial toilet or site. Savings per toilet estimates varied greatly across different commercial sites. As such, the estimate of mean savings per commercial toilet presented in this report may not extrapolate well to new commercial retrofits in Los Angeles. Extrapolation to other areas outside of Los Angeles would be more tenuous. Second, this study did not have access to indicators of the type of commercial toilet. Since flushometer-valve ULF toilets are typically much more expensive than the gravity-feed, tank type toilets used in the residential sector, the cost-effectiveness for commercial toilets will depend on the type of toilet installed. Analysis of data from a ULF toilet and urinal replacement program in public schools in Santa Monica suggest that each of these devices saved about 40 gallons per day—a level of effectiveness similar to a multiple family setting. Limitations of these data precluded separate estimates for toilets versus urinal savings. This makes this finding much weaker.

Despite these data limitations, this early evidence from the commercial and institutional sector is promising. The authors strongly urge water managers and planners to retain a healthy skepticism and require additional evidence from other geographical areas and other types of commercial sites.

Community-Based Organizations

An analysis of another type of targeted ULF toilet replacement program is presented in this report. Toilet rebate programs have generally been less successful in low-income communities, where the prospect of purchasing a toilet and waiting six to eight weeks for a rebate is less inviting. The Metropolitan Water District and its member agencies have been working with community-based organizations (CBO) to market and distribute ULF toilets in these areas. The first CBO program in Southern California was started in 1992 by the Mothers of East Los Angeles (MELA). Because this program represented the earliest chance for evidence on water savings, it was selected as a site for analysis.

The impact evaluation documented in the report estimated net water savings per household of 58.6 ± 14 gallons per day. (The level of uncertainty surrounding this estimate is larger due to the small sample size of participating households.) It appears that this level of savings is almost entirely explained by the greater number of persons per household (approximately 4.3). It is important to note that the higher level of water savings per household was achieved with a lower mean number of ULFs per household than was observed in the toilet rebate program (approximately 1.3 ULFs/HH in the MELA program as opposed to 1.5 ULFs/HH in the rebate program). Thus, the MELA program produced two distinct payoffs. Not only did this program replace ULF toilets in households unlikely to do so otherwise, the evidence also suggests a higher level of water saved from each replaced ULF toilet. Both findings strongly support the effectiveness of this CBO run program to replace ULF toilets. The extent to which this finding may be generalized to other CBO programs will depend on the characteristics of the targeted area.

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ACKNOWLEDGMENTS

Good statistical analysis cannot cure bad data. We would like to thank the staff of the City of Los Angeles and the City of Santa Monica for their assistance in providing, interpreting, and validating the data used in this analysis. We would specifically like to thank Samuel Hernandez, George Martin, and Susan Munves for freely sharing their knowledge, insights, and data with us. Their dedicated cooperation greatly helped in the construction of useful analytic questions.

This study could not have been carried out without the active cooperation of the Metropolitan Water District of Southern California (MWD). The MWD's belief in the value of conserved water as another way of ensuring a reliable supply of water has driven our analysis and quantification of conservation. In particular, special thanks go to Michael Moynahan and the staff of the State Water Project and Conservation Division for their unstinting support.

X

CONTENTS

FIGURES

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TABLES

I. INTRODUCTION

Why bother measuring the exact amount of water saved by a ULF toilet replacement? Everyone knows that ULF toilets use less water; why does it matter how much? If water agencies supported ULF toilet replacement solely for the purpose of good customer relations, then measurement of the water conserved by ULF toilets would be an academic exercise—probably painful, potentially edifying, and of doubtful practical worth. Much to the contrary, however, water agencies care deeply about how much water has been and can be saved by ULF toilet replacement. With California facing increasingly uncertain supplies of water, measuring the reliable "yield" from water conservation programs has taken on a new urgency. In the following sections we present the argument for measuring savings from water conservation programs.

Why Measure Water Savings?

Water conservation is essential to ensure the future reliability of water supplies. Conservation programs aim to reduce water demands and thereby increase the reliability of planned supplies of water. Conservation can thus be thought of as another "source" of water and, therefore, should be given the same level of attention as any other source of water supply. Conserved water cannot be counted on as a reliable water source if water managers lack a good estimate of potential savings. Hence, evaluation plays a crucial role in any conservation program.

The use of water conservation estimates in regulatory decision-making processes makes accurate evaluations even more important. Water is a public trust resource and, as such, is subject to public regulation. The estimates of water conservation find their way into water rights decisions made by regulatory bodies. As an example, the October 1988 draft "Water Quality Plan of the State Water Resources Control Board" estimated over one million acre-feet of conservation potential in California. This estimate was necessarily based on very limited data due to the very limited number of empirical studies of water conservation available at that time. Nonetheless, its use of "back-of-the-envelope" methods certainly drew additional controversy to the proposals of the draft Water Quality Plan. Improving regulatory decision-making stands as another important contribution of evaluation.

Finally, it is important to evaluate water conservation programs to learn what types of programs work best. If water managers know what works best within their range of conservation alternatives, they can improve current programs. More recently, the Memorandum of Understanding (MOU) Regarding Urban Water Conservation in California represents the agreement of signatories to implementing conservation "Best Management" practices. The inclusion of conservation practices in the BMP's turns directly on their cost-effectiveness. Evaluation is needed to define the "best" in Best Management Practices. Clearly, if water managers know which conservation measures provide the most "bang for the buck," they can better allocate scarce conservation resources.

Format of the Report

Section II describes the methods used in the impact evaluation. Section III then discusses the findings of the impact evaluation. The statistical models behind the estimates of water savings can be found in Appendix A. The models used to describe and explain (map) these savings can be found in Appendix B. Appendix C presents the models used to evaluate commercial and institutional ULF toilet replacements. Appendix D presents the models used to evaluation the low income CBO run ULF toilet distribution program. In Section IV the costs and benefits of ULF toilet programs are analyzed from the perspective of water agencies, customers, and the region. Section V presents the conclusions of this report.

II. METHODS

This section discusses the strengths and weaknesses of alternative evaluation methods and presents the statistical methods used in this report. Two widely used methods for estimating conservation—mechanical estimates and difference of means methods—are reviewed and found wanting. This section then discusses the empirical approach taken in this report using statistical models of customer billing data. Specifically, a formal definition of household water conservation is given—the difference between actual household water use and expected water use. This section then explains how statistical models can be used to derive an empirical estimate of expected water use and, thereby, a measure of conservation for each household in the study. By comparing the levels of conservation between participating households and nonparticipating households, one may arrive at an understanding of the net impact of the conservation program. Particular attention is paid to the confounding effect of the recent drought emergency and the voluntary and mandatory calls for reduction of water use.

Alternative Methods for Evaluating

Mechanical Estimates: Mechanical evaluation methods, also known as engineering estimates, are the simplest to perform and explain. Multiply the number of ULF toilets replaced by an assumption about the amount of water saved by each toilet. What could be simpler? We list five problems with mechanical estimates:

- not an empirical approach (no measurement involved),
- requires knowledge of things difficult to know (the weighted flow rate per flush of preexisting toilets),
- requires knowledge of unknowables (mean number of flushes per person),
- no allowance for behavioral changes, and
- no recognition of uncertainty.

Fundamentally, mechanical estimates can never be a method of evaluating water savings because they perform no measurement of reduced water use. Mechanical methods are a collection of assumptions that will always be subject to critique. The savings per ULF toilet, for example, depend on what type of toilet is being replaced. How many water agencies know the mix of 3.5 gallon per flush versus 5-7 gallon per flush toilets in their service area? What is the mean number of gallons per flush of 5-7 gallon per flush toilets? What is the prevalence of toilet displacement devices within each toilet category? And, above all, what is the mean number of flushes per person in a service area?

The rigid assumptions of mechanical estimates do not allow for behavioral changes. For example, ULF toilets may release less water with each flush, but people may be more inclined to double flush. Or, households that participate in a ULF toilet rebate program may increase their outdoor water use if water savings from the new toilets exceed voluntary or mandatory conservation goals.

The last empirical objection of the mechanical estimate concerns its handling of uncertainty. The parameters needed for a mechanical estimate are very uncertain. Worse, from a planner's perspective, mechanical estimates provide no means of reflecting or reporting this uncertainty. For example, estimates of the number of flushes per person per day range from three to five. The uncertainty in this parameter alone infuses a tremendous amount of uncertainty in mechanical estimates of conservation that are rarely reported. Similarly, dividing the mean number of person-flushes per household by the mean number of replaced toilets per household gives a biased estimate of the mean number of flushes per toilet[1].

We believe that mechanical estimates have a place in a water planner's tool box. They are cheap to perform, simple to explain, and are the only alternative at the pre-program stage when little data is available. Planners should, however, realize the inherent limitations of mechanical estimates and recognize that they do not constitute "evaluation." Mechanical estimates, though enticingly simple, can yield unreliable estimates of conservation.

Difference of Means Method: This method compares water use of a group of participants to the water use of a control group of nonparticipants that resemble

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[1]The technical argument behind this phenomena is provided in Mapping the Conserving effect of Ultra Low Flush Toilets: Implications for Planning, pp. 12-13. This report also documents statistical rejection of the constant per capita effect and the constant per toilet effects hypothesized by mechanical estimates.

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participants, on average, in terms of their household characteristics. Individuals are randomly assigned to one of two groups: the experimental group that receives the devices and a control group that does not. Since the two groups are otherwise assumed to be identical, any difference in water use between them can be attributed to the installation of conservation devices.

The difference-of-means method is analytically simple and requires only data on water use of the two groups. The simplicity of the technique and low data requirements account for its popularity. However, results from this method are valid only if the experimental and control groups resemble each other well. Unfortunately, in a non-laboratory setting this precondition is extremely difficult to achieve. Since conservation programs are voluntary, participants cannot be randomly assigned to experimental or control groups and, as a result, participant groups often differ from nonparticipant groups. Differential water use resulting from these household differences will be incorrectly attributed to the program. Without performing the difficult methodological work of randomizing and controlling ("designing") the experiment, the difference-of-means estimate can be substantially biased[2].

The above discussion highlights the inherent shortcomings of commonly used evaluation techniques. Numerous assumptions have to be made even when good data are available. Carefully performed statistical analyses can not only be more reliable, but they can also provide insights into program design by identifying the characteristics of households that saved more water and those that saved less. As a result, future programs can be better targeted and made more cost-effective. We turn to these statistical analyses next.

Empirically Defining Conservation

This study uses statistical models of household water use to empirically construct a definition for conservation—the difference between actual water use and expected water use. By making the appropriate comparison of the conservation observed among participants to that observed among nonparticipants, the models can

[2]We thoroughly discuss the problems with this method in a previous report, The Evaluation of Water Conservation Programs: What is Wrong with the Industry Standard Approach?, January 1991.

isolate the net effect of replacing ULF toilets in the midst of a drought emergency. The approach also takes into account unmeasured household characteristics that could affect water use. In analyses based upon survey data, it is always safer to assume that some household characteristics that affect water use remain unmeasured (e.g., attitudes toward water use efficiency) or mismeasured (e.g., the exact number of times a lawn is watered). In addition, several targeted programs — commercial, institutional, and CBO — are separately evaluated to ensure comparison to an appropriate control group.

<u>Gross Conservation versus Net Conservation:</u> A casual look at a household's historical water use would have trouble distinguishing between water saved in response to a specific retrofit program and water saved in response to the drought. Thus, even if one were able to exactly estimate how much water was saved by a particular conservation device in a particular home, this estimate would not answer the question: "How much water would that home have saved anyway?" During the period of study, Southern California was experiencing a severe drought emergency that included periods of voluntary and "mandatory" conservation.

Planners, in general, are held accountable for the net contribution of any publicly-funded program. If customers participated in a toilet retrofit program in *lieu* of other conservation, then these customers would exhibit no net water savings. Thus, it is conceivable to have a conservation program with no net effect. We derive a statistical estimates of net water savings from comparing the gross water savings of participants to the gross water savings of a control group that did not participate in the rebate program. The difference between gross savings of the participants and control households then is the estimate of the net impact of the conservation program.

<u>Different Control Groups:</u> The question of how much more water did participants in the ULF toilet rebate program save than they would have saved otherwise calls for a control group that closely matches the participant group. For this question, we use a control group of nonparticipants that might be better termed "pre-participants:" water use of participants is compared to water use of households that have not yet participated in the program (but do participate at a later date).

To answer the question of what nonparticipants would save if they participated, one must know whether there is any difference between those who have already participated and those who have not. This study uses a random sample of accounts from the billing system. This "random" control group should be representative of the service area. If participants are removed, the remaining accounts should be representative of nonparticipants.

Statistical Approach

The approach taken makes careful choices about (1) the historical period used to estimate statistical water use models, (2) the construction of appropriate measures to explain water use, and (3) what comparisons of use are to be made. Since the relationship of water use to household characteristics and climate could be different before, during, and after the drought, we adopt a three-step approach to estimating water savings.

Step 1: Estimate Water Use Models Using Pre-Program/Pre-Drought Data

We estimate models of household water demand using historical water use between January 1987 and June 1990. This represents a time period unaffected by large scale drought management programs or the ULF toilet rebate programs[3]. The water demand model relates individual account level water use to climate, seasonal patterns, household real-estate characteristics, household socio-demographic characteristics, and the price of water.

Since self-reported data collected through questionnaires inevitably contain errors, there is a reasonable basis for concern about the validity of statistical models based on these data. To address these concerns, we adopt a model estimation procedure that calibrates the demand model to each household to account for unmeasured or mismeasured characteristics of the household. Thus our model yields estimates of how household water use responds to household characteristics on average, and how individual households respond differently from the predicted average

[3]The determination of the exact time period for estimation was based on both *a priori* information from the water agencies involved and diagnostics performed by examining the effect of different estimation periods.

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response. These household-specific calibration factors yield substantially more accurate household-specific forecasts.

Step 2: Forecast Water Use in the Absence of the ULF Program

After estimating the water demand model, we used it to derive an estimate of "expected" water use during the drought and ULF program periods. This forecast provides a climate-corrected estimate of what water use would have been if the ULF program had not occurred. The total water saved by each household is then the difference between their actual water use and their model forecasted use. To illustrate, Figure III-1 plots the model forecast versus the actual historical mean water use of a sample of single family households that participated in the rebate program. Figure II-1 shows that the models fit the data very well during the historical pre-program period. Thereafter, the two curves begin to diverge as expected. Actual water use is less than the use we would expect (forecasted water use) because of the impacts of both the replacement of ULF toilets and the response to water shortage during the drought. These two impacts must be separated to obtain the net impact of the rebate program.

Step 3: Compare Conservation between Participants and Nonparticipants

Estimates of gross water savings between participants and nonparticipants (control group) are compared to address the question of how much more participants saved than they would have in the absence of the program. The comparison is performed through another set of statistical models that document (1) the net water savings per participating household, (2) explanations of why the amount of conservation varies among households, and (3) insights into future program targeting.

Roads not Taken

Regression models are generally used to evaluate by estimating over the entire available time period and including one indicator for participation. Why was this approach not taken? We offer three reasons. First, the one step modeling approach would confuse the response to drought with the estimated effect of climate. Thus, one would not be able to formally separate the two. Our model estimates the effect of climate in the pre-drought and pre-program period to obtain the most accurate estimate of climate's effect upon observed water demand. Second, the one step approach cannot discern levels of ongoing conservation. Thus, it cannot test for "snap-back" effects—customers using water conserved by ULF toilets to meet water cutback goals or to decrease their water efficiency vigilance. Third, the one step approach does not provide any explanation for why different households save different amounts of water. This type of insight is needed to improve the design of future water conservation programs.

Appendix A presents the specification and estimation of household water use models (Step 1) and forecasting water use through these models (Step 2). The findings from these models—Estimation of net water savings (Step 3)— is dealt with next in Section III. Appendix B presents the statistical models used to describe and explain the estimated household water conservation.

III. FINDINGS

This section presents the estimated water savings of households participating the first two years of ULF toilet programs in Los Angeles and Santa Monica. The first impact evaluation examined only the net water savings within the first year of the program; this report extends this analysis into the second year. Commercial, institutional, and CBO-run toilet replacement programs are treated separately.

Finding - Net Effect of Toilet Rebate Programs

One concern expressed by water planners was that the net impact of toilet replacement might dissipate in the 1991 period of mandatory water cutbacks. Due to supply curtailments, water agencies throughout Southern California moved beyond the 1990 calls for voluntary water reduction to programs enforcing mandatory water use reductions in 1991. LADWP instituted a mandatory program requiring 10 percent cutbacks beginning March 1, 1991 and 15 percent cutbacks beginning May 1, 1991. Any water use exceeding the conservation goal was subject to a higher penalty rate. (A household's 1986 water use served to define the base use against which conservation was defined.)

It is entirely conceivable that households might participate in ULF toilet programs to accomplish mandatory water reduction goals. Alternatively, households that had participated prior to March 1991 might not exhibit the same change in water using habits seen amongst nonparticipating households. Since the net impact of the ULF toilet rebate program is estimated by subtracting the level of (ongoing) conservation among nonparticipants from the level of conservation among participants, a constant level of participant conservation during times of elevated ongoing conservation could result in zero net water savings from a ULF toilet replacement program. First, did the level of ongoing conservation increase during 1991 and, if so, how much?

Figures III-1 and III-2 present the model estimates of ongoing conservation (model estimated expected water use minus actual water use) among single family and

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multiple family nonparticipants[4]. The levels of ongoing conservation per dwelling (the upper and lower uncertainty bounds represent a 95 percent level confidence interval) can be seen to increase immediately after institution of mandatory programs in March of 1991[5]. Single family residences demonstrate a higher level of conservation effort per dwelling than multiple family residences. This is believable for two reasons. First, water use per single family dwelling is higher to begin with than water use per multiple family dwelling. Thus there is a higher base from which reductions can be made. Second, outdoor water use forms a much greater share of water use in the single family sector. Outdoor water use is widely believed to have a larger discretionary component than indoor water use; the literature strongly supports higher response to price among outdoor end uses.

We may now ask whether the large increase in ongoing conservation obliterated the net effect of installing ULF toilets[6]. That is, did participants in the ULF rebate program increase their level of water savings to the same extent that nonparticipants did during the drought emergency?

[4]These descriptive estimates of ongoing conservation derive from a set of statistical models presented in Appendix B: total conservation for each household is explained by a different mean each month for participants and nonparticipants.

[5]The reader should note that gaining a true understanding of the time scale in the graphs requires some effort. Each point in the graph represents an average estimated across all nonparticipating accounts. Since water meters are read approximately every 61 days and meter readers require two months to read all meters in the service area, the time scale must also cover two months to contain all accounts. Thus, the tick marked March 1991 would most accurately be termed 61 day measures of water use from meters read in March and April. Because each meter read represents the prior 61 days of water use, water meters read in March represent water use distributed across January, February, and March. The collection of water meters read in March and April represent water use distributed across January, February, March, and April. March 1 is the approximate calendar day center of this distribution of water use. The dramatic increase in ongoing conservation, visible on the March 1991 tick, accords with the fact that the mandatory program was announced in February and given great media attention. Readers should take care not to overinterpret calendar time in the graphs that follow.

[6]This report does not address the issue of the relative worth of conserved water within a drought emergency versus during a nonemergency period. If there are costs to storing water or if there are finite storage or conveyance limits, the water conserved during an emergency period would presumably have higher worth than water conserved in a nonemergency period. In the cost effectiveness analysis that follows, we add no additional premium for the additional value of water conserved during an emergency.

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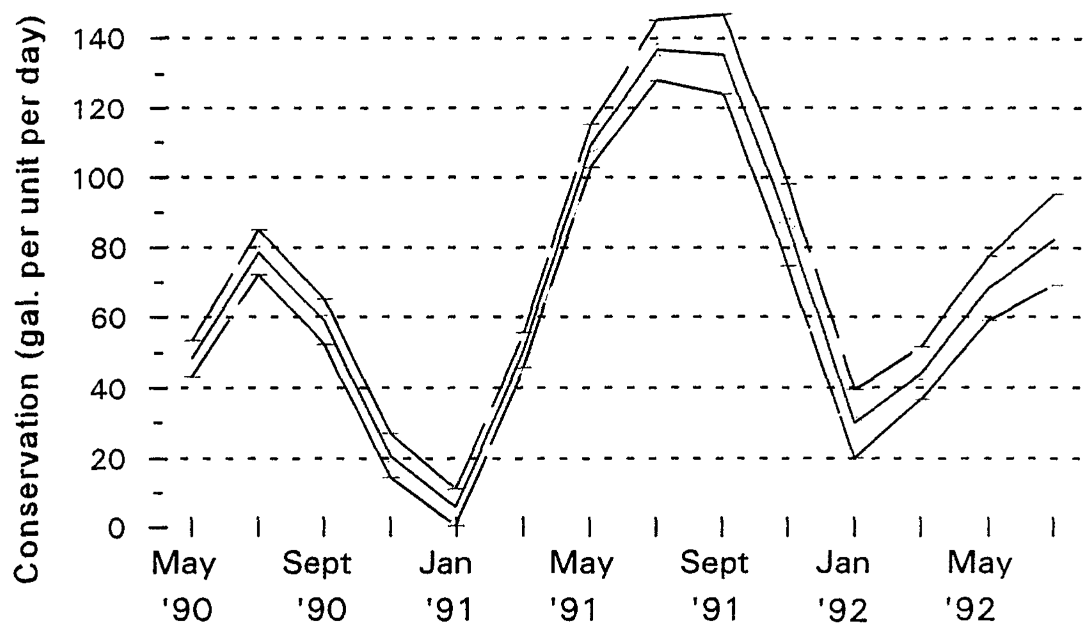

Figure III-1: Single Family Nonparticipants - Ongoing Conservation.

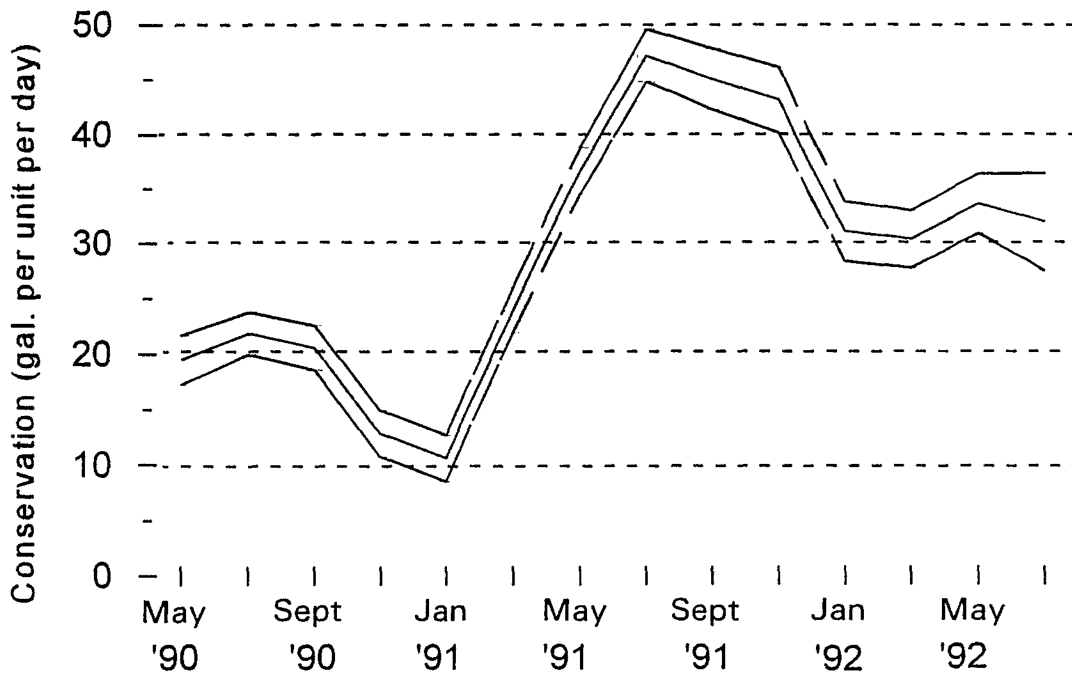

Figure III-2: Multiple Family Nonparticipants - Ongoing Conservation.

Figures III-3 and III-4 present the model estimates of net conservation among single and multiple family participants[7]. Though some suppression of the net level of water savings can be observed in the early period of mandatory water cutbacks[8], the level of net water savings per household appears to stabilize among single family participants and actually increase among multiple family participants. The estimated average net conservation (with uncertainty bounds expressed as 95 percent level confidence interval) is presented below in Table III-1.

Table III-1 Average Net Savings per Dwelling in Gallons per Dwelling per Day (Uncertainty range in parentheses)

Single Family Households	41.2 (38.4 - 44.0)
Multiple Family Units	44.0 (42.7 - 45.2)

Does this mean that the cost-effectiveness of the programs remained constant for single family households and increased among multiple family units? Not necessarily. Since the costs of rebate programs are closely tied to the number of toilets rebated, the cost-effectiveness depends directly on the number of replacements per dwelling. As the ULF rebate programs continued, second year participants tended to perform a more complete replacement of toilets in the household: the mean number of replaced toilets per household went up from 1.3 to 1.5 toilets per single family household and from 0.7 to an average of about 1.0 toilets per multiple family unit[9].

[7]See descriptive models in Tables B-1 and B-2 of Appendix B "Models to Describe and Map Conservation".

[8]It could be hypothesized that the greatest "pure" behavioral component of a response to a water emergency would occur early and diminish over time. This would be consistent with the evidence presented here. Though the absolute level of conservation did increase through the summer of 1991, the percent effect did decline over time.

[9]Note the distinction between a multiple family complex and a multiple family unit. If a multiple family complex had 10 dwelling units and replaced 7 of 10 toilets, the average number of installed toilets would be 0.7 toilets per dwelling unit.

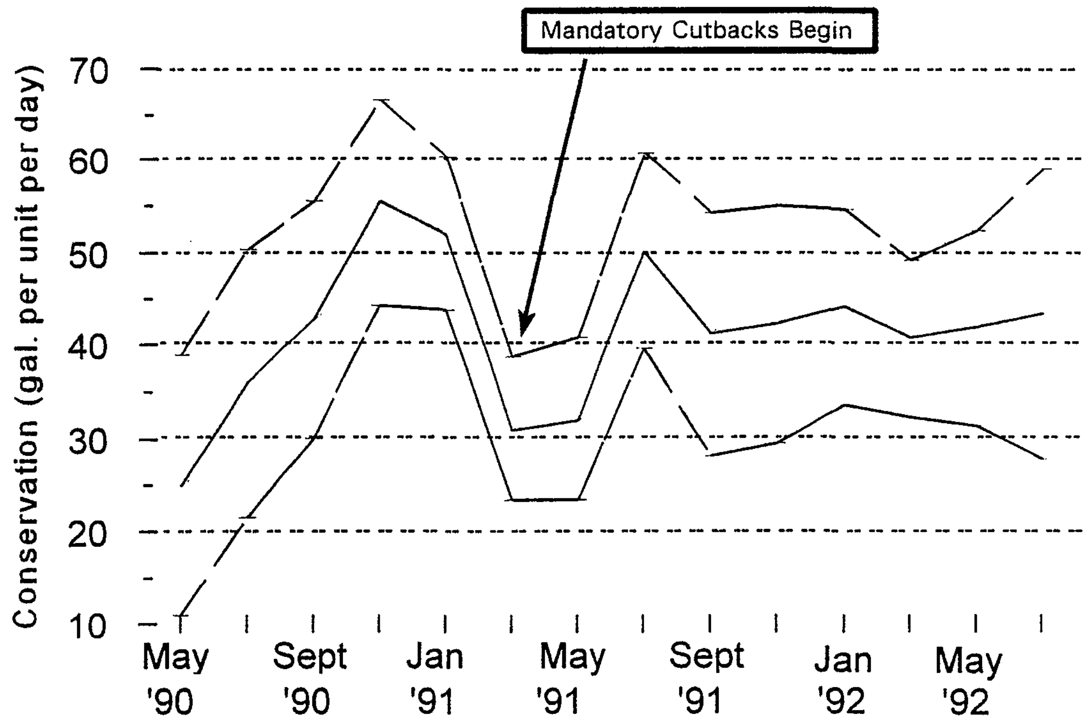

Figure III-3: Single Family Participants - Net Conservation.

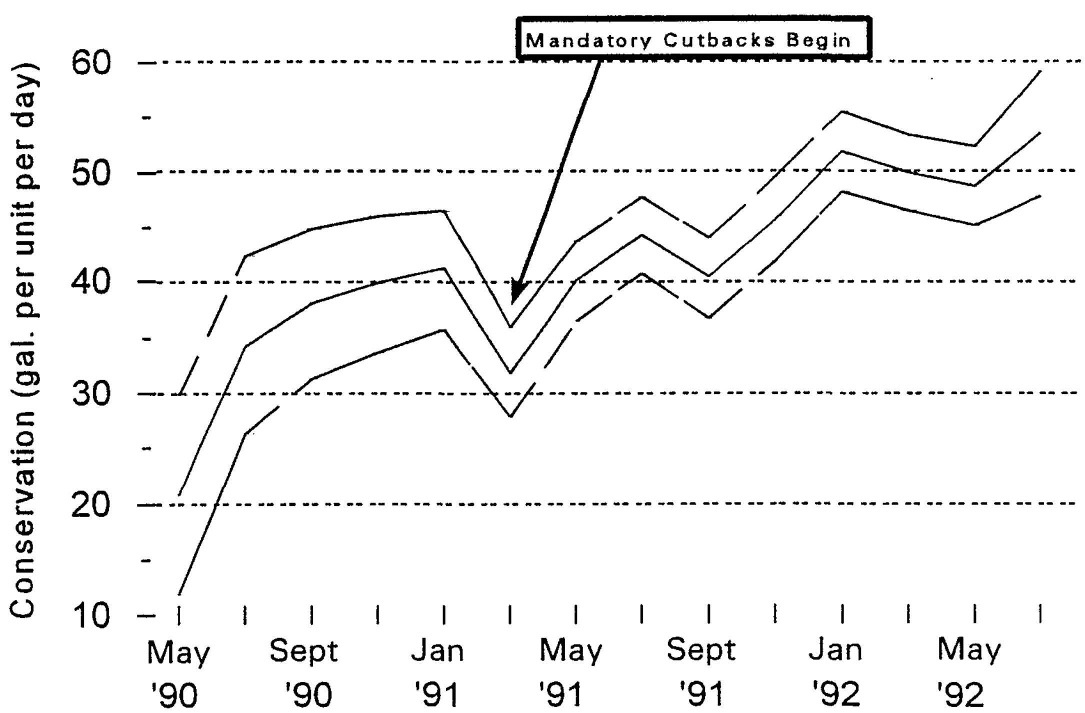

Figure III-4: Multiple Family Participants - Net Conservation.

Arriving at an estimate of the savings per ULF toilet requires more than dividing Table III-1 by the mean number of installed toilets per household. The net household savings in Table III-1 also reflect installation of low-flow showerheads when they were not already present. Table III-2 provides the estimated savings per device derived from statistical models that explain ("map") per household conservation by the number of toilets replaced, the number of low flow showerheads replaced, and the number of people living in the household.

Table III-2 Estimated Net Savings per ULF Toilet and Low-Flow Showerhead in Gallons per Device per Day

	Savings per ULF Toilet	**Savings per LF Showerhead**
Single Family Households	21.6	5.5
Multiple Family Units	40.3	5.2

The reader should note that the estimated savings per ULF toilet replaced over the two year period of this study are somewhat lower than the levels reported among first year participants examined in the first impact evaluation[10] (28 gallons per ULF toilet in single family residences and 44 gallons per ULF in multiple family residences.) These lower levels of water savings, if program costs remained the same, imply a slight decline in the cost-effectiveness of these ULF rebate programs. We believe that much of this change in the savings per toilet can be understood by the increasing number of second and third toilets in the mix of replaced toilets. The first study found that households replacing two toilets did not save twice as much as households replacing one toilet. We turn next to the issue of the declining marginal effectiveness of toilet replacement.

[10]Chesnutt et al., The Conserving Effect of Ultra Low Flush Toilet Rebate Programs, June 1992, p. iv.

Finding - The First Toilet Saves the Most

For lack of quantifiable information, managers of ULF toilet rebate programs have been forced to assume that water savings per retrofit are equal, although common experience clearly indicates otherwise; not all toilets within a home are used with the same intensity. The data used in the first impact evaluation showed that indeed water savings per replacement declined as more toilets are retrofitted in a dwelling. This declining marginal effectiveness of toilet replacement was more pronounced for single family households than for multiple family units.

For the single family sector, Table III-3 gives evidence on how the savings per toilet can vary[11]. The first point to note is that the savings per toilet tends to decline as more toilets are replaced. Some have suggested that households replacing only one toilet might place the untested ULF toilet in the least used bathroom. Table III-3 would support contrary hypotheses that households replacing only one toilet tend to replace the oldest, highest use, or possibly leaking toilet. The increasing number of second and third toilets being installed by participants in the toilet rebate program will tend to lower the mean per toilet savings estimate.

Table III-3 Mean Savings per Toilet By Number of ULF Toilets Replaced

	Single Family: Savings per ULF Replaced			
	Number of ULFs Replaced			
	1 ULF	2 ULFs	3 ULFs	
1 Toilet in Household	24.2			Gallons per Day per ULF Toilet
2 Toilets in Household	33.7	20.8		
3 Toilets in Household	45.9	36.1	20.1	
Mean Effect	29.9	20.6	19.1	
Note: The Mean Effect (last row) is taken across all households and includes some households with more than three toilets. Thus it cannot be directly derived from the rows above.				

[11]Table III-3 differs from the tables presented in the previous evaluation: Table 6 (The Conserving Effect of Ultra Los Flush Toilet Rebate Programs, p. 14) presented mean savings per household; Table III-3 presents mean savings per ULF toilet.

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The second point to note is how household characteristics can affect the savings per toilet. The household characteristics of those who live in homes that have only one toilet can be very different from the characteristics of homes having three toilets. Table III-3 provides the further breakdown of savings per toilet by the number of toilets in the home.

Table III-4 provides estimates for the level of water savings per multiple family ULF toilet replacement that suggests a more gradually declining marginal effect[12].

Table III-4 Mean Savings per Toilet By Number of ULF Toilets Replaced

	Multiple Family: Savings per ULF Replaced		
	Number of ULFs Replaced per Unit		
	Up to 1 ULF per unit	More than 1 ULF per unit	
All Multiple Family Units	44	34	Gallons per Day per ULF Toilet

Finding - Commercial ULF Toilet Replacement

Based on a relatively small sample of about two hundred and fifty commercial sites, we estimate a mean savings of 73.6 ± 3 gallons per ULF toilet replaced. Several cautionary notes should be made. First, there is no such thing as an "average" commercial toilet or site. Savings per toilet estimates varied greatly across different commercial sites. As such, the estimate of mean savings per commercial toilet presented in this report may not extrapolate well to new commercial retrofits in Los Angeles. Extrapolation to other areas outside of Los Angeles would be more tenuous. Second, this study did not have access to indicators of the type of commercial toilet. Since the purchase and installation of flushometer-valve ULF toilets are typically much

[12]Because multiple family complexes are typically master metered and the number of units per complex varies greatly, no detailed breakout of per toilet savings by the number units in the complex is attempted. Exploratory analysis revealed no statistically distinguishable differences in conservation by the number of units in a multiple family complex.

more expensive than the gravity-fed, tank type toilets used in the residential sector, one must know the mix of installed toilets to derive an unbiased estimate of cost-effectiveness.

Analysis of data from a ULF toilet and urinal replacement program in public schools in Santa Monica suggest that each of these devices saved about 40 gallons per day—a level of effectiveness similar to a multiple family setting. Limitations of these data precluded separate estimates for toilets versus urinal savings. This makes this finding much weaker.

Despite data limitations, this early evidence from the commercial and institutional sector is promising[13]. The authors do, however, strongly urge water managers and planners to retain a healthy skepticism and require additional evidence from other geographical areas and other types of commercial sites.

Finding - Community-Based Organizations

This section presents an analysis of another type of targeted ULF toilet replacement program. Toilet rebate programs have generally been less successful in low-income communities, where the prospect of purchasing a toilet and waiting six to eight weeks for a rebate is less inviting. The Metropolitan Water District and its member agencies have been working with community-based organizations (CBO) to market and distribute ULF toilets in these areas. In this type of targeted effort, the CBO organizes and administers a program to provide ULF toilets to residents at no charge. Metropolitan and the sponsoring member agency subsidize the toilet purchase and provide a $25 incentive to the CBO for each replaced toilet. The CBO markets the program in its community, distributes the toilets, provides technical trouble-shooting for installation problems, and collects the old toilets for recycling. Proceeds from ULF toilet programs have been used by CBO's to support graffiti removal, child-care, scholarship funds, and job training. There are now eleven CBO programs that have distributed over 65,000 ULF toilets. By providing another means for raising money for community

[13]The City of San Diego recently installed over 300 toilets at 70 public facilities. The mean savings per toilet was estimated at 76.8 gpd. Many of these facilities could be characterized as high traffic, high use sites. Thus, the attempt to generalize this result should apply only to similar areas. See Bamezai, A. and Chesnutt, T. (1994).

needs, these ULF toilet programs have been able to enlist community support and achieve higher levels of ULF toilet replacement.

CBO programs have somewhat greater program expenses per replaced ULF toilet. If ULF toilets save as much water in these communities as elsewhere, these slightly higher programs costs may be justified as the cost of attaining market penetration in difficult-to-reach areas. On the other hand, many have argued that toilets replaced through CBO programs in low-income areas should expect higher levels of savings. Residences in these areas are older and more densely populated. Older homes tend to have older toilets; older toilets use more water due to design and potentially higher levels of leaks. More persons per household imply more people using each toilet. This higher usage level should result in higher savings for each toilet replaced with a higher efficiency device. Do ULF toilets replaced by CBO programs save as much or more than ULF toilets replaced through rebate programs?

The first pilot CBO program in Southern California was started in 1992 by the Mothers of East Los Angeles (MELA). Because this program represented the earliest chance for evidence on water savings, it was selected as a site for analysis. Based on survey data on household characteristics collected by MELA, an impact evaluation of billed water use was conducted. Following the same methodology used in the rebate impact evaluation, a model of household water demand (documented in Appendix E) was estimated in a pre-drought, pre-program period. Forecasts from the model of water demand were used to estimate "expected" water use during the program period. By comparing the water savings of participants to pre-participants, an estimate of the net program impact is obtained.

The impact evaluation documented in the report estimated net water savings per household of 58.6 $\pm$ 14 gallons per day. (The level of uncertainty surrounding this estimate is larger due to the small sample size of participating households.) It appears that this level of savings is almost entirely explained by the higher number of persons per household (approximately 4.3). It is important to note that the higher level of water savings per household was achieved with a <u>lower</u> mean number of ULFs per household than was observed in the toilet rebate program (approximately 1.3 ULFs/HH in the MELA program as opposed to 1.5 ULFs/HH in the rebate program). This suggests two distinct payoffs from ULF programs run by CBOs. Not only do these programs replace ULF toilets in households unlikely to do so otherwise, the evidence also suggests a higher level of water saved from each replaced ULF toilet. Both findings strongly support CBO run programs to replace ULF toilets.

Additional Findings - Effect of Meter Replacement

Due to wear and tear, water meters become less sensitive to water flow with age. As a result, old meters tend to under-register water consumption. Water agencies have implemented meter replacement programs to both increase the fairness of water bills and to improve the price signal given to customers. The estimated water demand models in Appendix A provide an empirical estimate of the magnitude of this effect. Metered water consumption in single family homes increased by 7.9 percent after a meter was retrofitted, about 35 gallons per day per household. Measured water use per multiple family unit increased by 10.8 percent upon meter replacement, about 24 gallons per day per unit. Since meter replacement programs are implemented, in part, as a water conservation effort, these empirical estimates can be used to justify and determine the cost-effective level of effort for these programs.

Additional Findings - Effect of Price

The estimated demand models used in this study (contained in Appendix A) also provide estimates of the "pure" effect of price upon water demand. That is, the behavioral response to changes in price that does not include installation of conservation devices. The estimated response to price depends upon outdoor water use. Figure III-5 presents a graphical depiction of the price elasticities in the single family household water demand model. Households having more outdoor irrigated area exhibit a larger percent response to price.

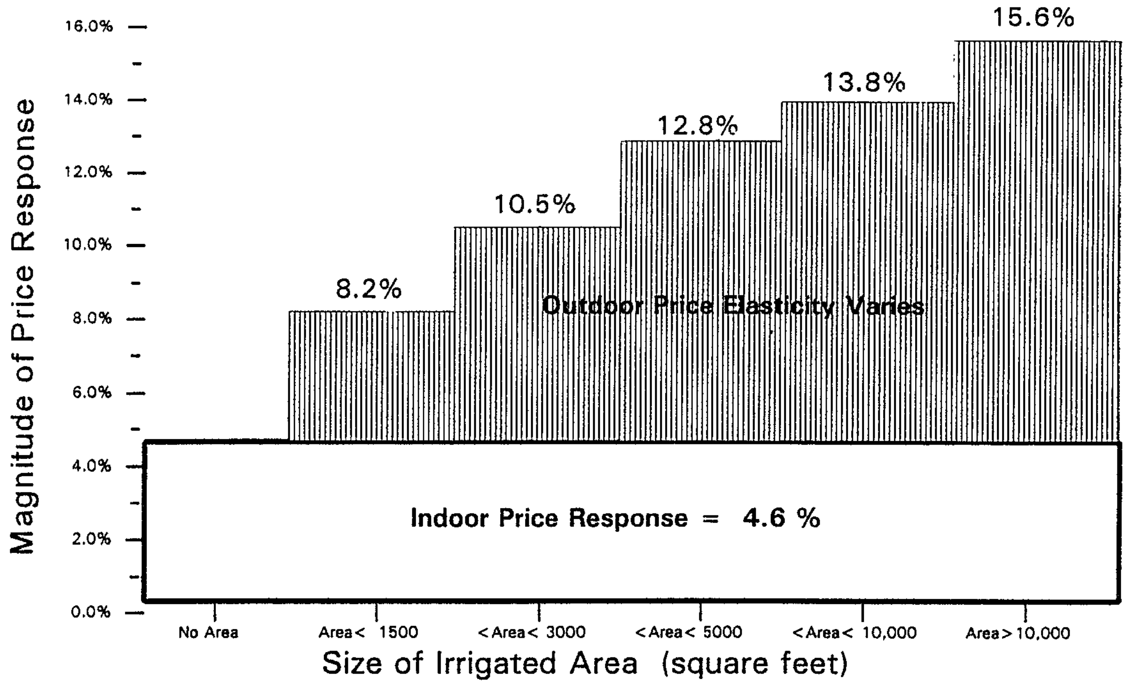

Figure III-5: Single Family Households Estimated Price Elasticities

The water demand model for multiple family complexes exhibit similar patterns, with complexes having no significant outdoor water use showing smaller responses to price. This finding should not be very surprising; it has long been believed that indoor water uses are less discretionary and less responsive to changes in price. The finding that the price response increases with increasing outdoor water use also has implications for what constitutes a "good" rate design and the revenue effect of changing to an inclining block rate structures. Note that the estimated price elasticities are short-run response, and as such, represent the lower bound of what can be expect to occur over the long run.

IV. COST-BENEFIT ANALYSIS

To consider water conservation programs as reliable sources of future water supply, the "yield" from conservation programs must be shown to be cost-effective. This section translates the estimated net water savings from ULF toilet replacement programs into estimates of benefits that may be compared with program costs. The task of valuing the stream of benefits is considerably more difficult than the task of estimating costs. The costs are incurred immediately and are denominated in current currency. The benefits, by contrast, occur over a period of time and derive from the quantity of water saved. We examine these issues from different perspectives--the water agency, customers, and regionally.

Costs and Benefits from A Water Agency's Perspective

Common assumptions are key to consistent broad based planning; relative differences in planning alternatives should not result from the use of different sets of assumptions. We use two common assumptions from the current Integrated Resources Planning (IRP) process at Metropolitan. The first assumption common to the IRP process relates to the time value of money. If a water agency were to borrow money, what rate of interest would it be required to pay in real, or inflation-adjusted terms? The discount rate used in Metropolitan's IRP is six percent per year. The second common assumption relates to the future value of water. Metropolitan's IRP incorporates the planning assumption that the real cost of new water will increase over time. The assumption common to all planning calculations is an escalation in the future (real) cost of water of four and one half percent per year.

How can these assumptions be used to compare costs that occur immediately at the time of replacement with the water-saving benefits that accrue over the physical lifetime of a toilet—generally assumed to be around 20 to 30 years. Table IV-1 presents an example of calculations required to compute the present value of water conserved from ULF toilet replacement over an assumed 20 year physical toilet life[14].

[14]We believe that 20 years is a lower bound for the physical life of a toilet.

Table IV-1 Estimated Net Present Value of Benefits per Single Family ULF Toilet Replacement

Year	Water Savings (AF/yr) [1]	Future Price ($/AF) [2]	Value of Water Produced ($/yr) [3]	Discounted Value of Water ($/yr) [4]
1	0.02419	$406.51	$9.83	$9.28
2	0.02419	$424.80	$10.28	$9.15
3	0.02419	$443.91	$10.74	$9.02
4	0.02419	$463.89	$11.22	$8.89
5	0.02419	$484.76	$11.73	$8.76
6	0.02419	$506.58	$12.25	$8.64
7	0.02419	$529.38	$12.81	$8.52
8	0.02419	$553.20	$13.38	$8.40
9	0.02419	$578.09	$13.98	$8.28
10	0.02419	$604.11	$14.61	$8.16
11	0.02419	$631.29	$15.27	$8.05
12	0.02419	$659.70	$15.96	$7.93
13	0.02419	$689.38	$16.68	$7.82
14	0.02419	$720.41	$17.43	$7.71
15	0.02419	$752.82	$18.21	$7.60
16	0.02419	$786.70	$19.03	$7.49
17	0.02419	$822.10	$19.89	$7.39
18	0.02419	$859.10	$20.78	$7.28
19	0.02419	$897.76	$21.72	$7.18
20	0.02419	$938.16	$22.70	$7.08
			Total Present Value, Σ =	$162.60

Notes:
[1] Savings per single family ULF is 0.0241915 AF/yr (=21.6gpd*365days/325900gl/AF).
[2] Value of Water in initial period (t=0) is 389 $/AF, Escalation Rate is 4.5 percent.
[3] = [1] x [2].
[4] = [3] / (1+r)^t ; where r, the discount rate, is 6.0 percent.

Table IV-1 suggests that the present value of the conserved water over a 20 year period is $162.60. Since the direct program cost to the water agency have been less than $125, the calculated benefits are greater than the costs[15].

Calculating the present value, as demonstrated in Table IV-1, is a tedious affair. Instead of discounting each year and summing across years, is there a simpler way to convert the constant stream of benefits (i.e., the water saved by the toilet given in Column [1] of Table IV-1) into a present value? One approach converts the physical life of a toilet into an "economic" life. Since the monetary value of water savings that accrue in the future is less than the monetary value of water savings achieved today, the effective economic life of a toilet is less than its physical life. At very high discount rates, the economic rate can be much shorter than the physical life.

To illustrate, the economic life of the toilet in Table IV-1 is the total benefit divided by the undiscounted annual benefit, i.e., $162.60 ÷ (.02419AF/yr*389$/AF) = 17.3 years. If one had a formula to convert discount assumptions into an economic life, the present value calculation would simply be the value of the benefit (in current dollars) times the economic life. Fortunately, such a formula can be derived. The formula consistent with Table IV-1 is:

$$E \equiv \frac{(1+i)^n - 1}{(1+i)^n \cdot i}$$

There are several variants of this simple rule. The different variants come from different assumptions about when the discounting begins. One formula results if the valuation occurs at the beginning of the period, another if the valuation occurs at the end of the period. Since questions arose to the version used in the cost effectiveness calculations of the first impact evaluation (<u>The Conserving Effect of Ultra Low Flush</u>

[15]Program costs for smaller scale programs could be higher. Program costs for the Los Angeles DWP have declined somewhat due to a reduced inspection schedule. Per toilet program costs for the City of Santa Monica may have slightly increased since the inception of their program due to a reduced scale of operations. CBO program costs have not differed greatly from the rebate program costs. The estimate of $125 dollars per ULF toilet represents an upper bound for the residential ULF programs evaluated in this report.

Toilet Rebate Programs, p. 11), a derivation is provided below[16]. To enact the calculation, one need only compute the "net" result of using an escalating cost of water, ***e***, and a discount rate for the time value of money, ***r***. That is, find the rate *i*, such that:

$$\frac{1}{1+i} = \left(\frac{1+e}{1+r}\right); \qquad \rightarrow i = \left(\frac{1+r}{1+e}\right) - 1$$

Thus, the short-cut to computing the economic life of a ULF toilet in a single family household uses a discount rate of 1.435 percent (=(1.06/1.045)-1) in the

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[16]If the annual discount rate is ***r***, the water saving benefits occurring one year from today $\mathbf{B_1}$ are worth $\mathbf{B_1/(1+r)}$, benefits occurring two years from today $\mathbf{B_2}$ are worth $\mathbf{B_2/(1+r)^2}$, and in general benefits occurring ***n*** years from today are worth $\mathbf{B_n/(1+r)^n}$. If the benefits over time are constant ($\mathbf{B_1 = B_2 = \ldots = B_n}$), we can arrive at the following expression for the sum of benefits over ***n*** years:

$$PresentValue = \frac{B_1}{R} + \frac{B_2}{R^2} + \ldots + \frac{B_n}{R^n}\ ;\ R \equiv (1+r)$$

or

$$B \cdot E = B \cdot \left(\frac{1}{R} + \frac{1}{R^2} + \ldots + \frac{1}{R^n}\right);\ where \quad B_1 = B_2 = \ldots = B_n$$

A simple expression can now be derived for **E**, the economic life of the benefits:

$$E = \frac{1}{R} + \frac{1}{R^2} + \ldots + \frac{1}{R^n}\ ;\ where\ R \equiv (1+r)$$

Divideby*R*,

$$\frac{E}{R} = \frac{1}{R^2} + \frac{1}{R^3} + \ldots + \frac{1}{R^{n+1}}$$

and subtract the two equations,

$$E - \frac{E}{R} = \left(\frac{1}{R} - \frac{1}{R^{n+1}}\right)$$

$$E \cdot \left(1 - \frac{1}{R}\right) = \left(\frac{1}{R} - \frac{1}{R^{n+1}}\right)$$

$$E = \frac{\left(\frac{1}{R} - \frac{1}{R^{n+1}}\right)}{\left(1 - \frac{1}{R}\right)} = \frac{\left(1 - \frac{1}{R^n}\right)}{(R - 1)} = \frac{R^n - 1}{R^n \cdot (R - 1)} = \frac{(1+r)^n - 1}{(1+r)^n \cdot r}$$

formula to compute the economic life[17]. Substituting into the (end-of-period) formula for the economic life, yields the estimate of 17.3 as the economic life of a ULF toilet. (Using the beginning of period formula yields an estimate of 17.5 years that is not practically very different[18].)

Rather than compare benefits to costs, the discounting assumptions can also be used to generate estimates of cost-effectiveness. A single family toilet saving .024 acre-feet of water per year will, over its economic life, save .4185 acre feet (=.02419 AF/yr x 17.3 years) at a direct cost to water agencies of $125. This works out to a cost of approximately 299 $/AF ($125 ÷ .4185 AF) for the economic life of the toilet. Table IV-2 provides estimates of the cost-effectiveness of water saved from ULF toilet replacements from a "narrow" water agency perspective. This perspective is narrow because it only includes direct costs to water agencies.

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[17]The reciprocal of the economic life is also known as a capital recovery factor—the annual fraction of total capital investment that must be recovered in even nominal amounts over the period of investment.

[18]If the benefits are valued at the beginning of the investment period, the relation is:

$$\mathit{PresentValue} = B_1 + \frac{B_2}{R} + \ldots + \frac{B_n}{R^{(n-1)}} \; ; \; R \equiv (1+r)$$

or

$$B \cdot E_0 = B \cdot \left(1 + \frac{1}{R} + \ldots + \frac{1}{R^{(n-1)}} \right); \; \textit{where} \;\; B_1 = B_2 = \ldots = B_n$$

and a slightly different formula for the economic life results.

$$E_0 - \frac{E_0}{R} = \left(1 - \frac{1}{R^n} \right)$$

$$E_0 \cdot \left(1 - \frac{1}{R} \right) = \left(1 - \frac{1}{R^n} \right)$$

$$E_0 = \frac{\left(1 - \frac{1}{R^n} \right)}{\left(1 - \frac{1}{R} \right)} = \frac{\left(R - \frac{1}{R^{n-1}} \right)}{(R - 1)} = \frac{R^n - 1}{R^{n-1} \cdot (R - 1)} = \frac{(1+r)^n - 1}{(1+r)^{n-1} \cdot r}$$

This was the formula used in the first impact evaluation. We now use the end-of-period valuation in this evaluation since it yields a slightly shorter economic life and we desire a conservative upper bound on the cost-effectiveness of ULF toilet replacements. Planners desiring neither an upper nor a lower bound can also use the variant of the formula that performs the valuation of benefits at mid-year, using the time index (***n***-½). If the time stream of benefit is well defined and important, greater resolution can be obtained by using a smaller time step, that is, monthly or weekly indices.

Table IV-2 Cost Effectiveness to Water Agencies: Estimated Cost per Acre Foot from ULF Toilet Replacement

Type of Toilet Replacement	Savings per Toilet (gpd) [1]	Savings per Toilet (AF/yr) [2]	Direct Cost per Toilet ($/ULF) [3]	Cost of Saved Water r=.06 ($/AF) [4]	Cost of Saved Water r=.06, e=.045 ($/AF) [5]
Single Family	21.6	0.0242	$125.00	$450.49	$298.68
Multiple Family	40.3	0.0451	$125.00	$241.45	$160.08
Commercial	73.6[§]	0.0824	$125.00	$132.21	$87.66
Low Income CBO	45.1	0.0505	$125.00	$215.76	$143.05

Notes:
[1] Water Saved per ULF toilet replacement in gallons per day (gpd).
[2] = [1] x 365 days ÷ 325,900 gallons per acre foot.
[3] Direct cost to water agencies per toilet replaced.
[4] = [3] ÷ ([2] x 11.5 economic years).
[5] = [3] ÷ ([2] x 17.3 economic years).
[§]*This estimated level of savings should be considered provisional and reflective only of* the sample of commercial accounts examined in this report.

The cost-effectiveness calculations presented in Table IV-2 allow water conservation programs to be directly compared with new water resource development alternatives. The assumptions going into these calculations may vary in different water agencies, as may the range of alternatives for developing new water sources. Even so, the narrowly-defined and rather conservative cost-effectiveness calculations indicate that the development of existing water resources through ULF toilet programs is attractive when compared with many of the alternative new water sources[19].

[19]These calculations reflect the replacement of an individual ULF toilet. To calculate the net effect of a ULF toilet program requires additional system-wide assumptions about the natural rate of replacement of existing toilets. The CUWCC-approved document, Assumptions and Methodology for Determining Estimates of Reliable Water Savings from the Installation of ULF Toilets, illustrates an example of such a system wide calculation of the net effect of ULF toilet replacement that accounts for the ongoing rate of toilet replacement. Given the recent California law restricting new toilet sales to be of the 1.6 variety, it is important to control for the rate at which old toilets would be replaced with ULF toilets in the absence of toilet programs.

Costs and Benefits from A Customer's Perspective

Customers are likely to have a different perspective on both costs and benefits. The direct costs to the water agency do not include the time and expense to install the toilets or any portion of the purchase price greater than the rebate amount. Based on inspection data for single family homes, we assume a $50 installation cost and a mean toilet purchase price of $130 per ULF toilet[20]. For multiple family complexes, we assume a $25 installation cost and a $100 mean purchase price[21]. For commercial participants, we assume an $80 installation cost and a $170 mean purchase price per toilet[22].

The customer perspective on the present value of benefits is more involved for two reasons. First, the cost the customer pays includes sewer charges that vary directly with the volume of water used. Thus, the marginal rate paid by customers for each additional unit of water must include sewer charges. Second, many customers may be unaware that water agencies are expecting an increasing real price of water in the future. Further, households have been shown to exhibit very high (inferred) internal discount rates for making decisions about energy conserving household equipment

[20]In the first impact evaluation, a common installation cost was assumed for all types of toilets. The modal response for single family participants who did not install the toilet themselves, was $50 per toilet. We choose the conservative assumption that the opportunity cost for self-installers was equivalent.

[21]The inspection form data for installation cost is more ambiguous for multiple family complexes. Some respondents reported total installation cost for the complex. A greater proportion self-installed toilets. It does appear, however, that there were economies of scale in the multiple family sector that resulted in a lower per toilet installation cost.

[22]The purchase cost estimate comes from a direct installation program in the City of Santa Monica and assumes that all installed commercial ULF toilets were flushometer valve-type. Since both flushometer-valve and gravity-fed toilets are used in commercial applications, the $170 purchase cost estimate should be thought of as an upper bound. The installation cost for commercial toilets are higher to reflect the additional plumbing reconfiguration sometimes required in commercial applications.

(Hausman, 1979)[23]. It would not be difficult to believe that households would exhibit similar patterns when making decisions about water conserving household equipment.

We will perform the cost benefit calculations making two sets of discounting assumptions—1) customers discount exactly as do the water agencies (a 1.4 percent net discount implying a 17.3 year economic life) and 2) customers exhibit higher net discount rates(a 8 percent net discount that implies a 9.8 year economic life). Table IV-3 exhibits the cost-effectiveness calculations from a customers' perspective.

To illustrate the attractiveness of water conserved from ULF toilet replacement consider that many LADWP residential customers are currently paying combined sewer and water rates of over three dollars ($1.367 sewer rate and $1.71 water rate in the lower block) per hundred cubic feet of water. This works out to a price of over $1,340 per acre foot (= $3.077 $/HCF × 435.6 HCF/AF). Even ignoring the residential customers facing a higher water rate (those having a higher level of water use that falls into a higher rate block), ULF toilet replacement should appear very attractive, even at high rates of discounting.

[23]The requirement for a short pay-back does not make sense if the only element in the decision-making calculus were a known set of benefits and costs. In a world where information is not perfect and much is uncertain, this behavior becomes more readily understandable. One of the major results of the literature on investment under uncertainty is that rational decision makers should use a higher discount rate in an uncertain world than in a certain world. Discounting risks, by using a higher internal rate of return, is akin to looking hard before you leap.

Table IV-3 Customer Cost Effectiveness: Estimated Cost per Acre Foot from ULF Toilet Replacement

Type of Toilet Replacement	Savings /Toilet (gpd) [1]	Savings /Toilet (AF/yr) [2]	Toilet Cost ($) [3]	Install-ation Cost ($) [4]	Rebate ($) [5]	Net Cost /Toilet ($) [6]	Customer Cost 17.3 years Economic Life ($/AF) [7]	Customer Cost 9.8 years Economic Life ($/AF) [8]
Single Family	21.6	0.024	$130	$50	$100	$80	$191.15	$337.44
Multiple Family	40.3	0.045	$100	$25	$75	$50	$64.03	$113.04
Commercial	73.6$	0.082	$170	$80	$100	$150	$105.19	$185.69
Low Income CBO	45.1	0.051	$0	$50	$0	$50	$57.23	$101.03

Notes:
[1] Water Saved per ULF toilet replacement in gallons per day (gpd).
[2] = [1] x 365 days ÷ 325,900 gallons per acre foot.
[3] Toilet Purchase Price.
[4] Installation Cost.
[5] Cash Rebate for Toilet.
[6] = [3]+[4] − [5], Net Cost to Customer.
[7] = [6] ÷ ([2] x 17.3 economic years), Assumes 1.4 percent net discount rate.
[8] = [6] ÷ ([2] x 9.8 economic years), Assumes 8 percent net discount rate.
$This estimated level of savings should be considered provisional and reflective only of the sample of commercial accounts examined in this report.

Costs and Benefits from A Regional Perspective

The regional perspective must include all costs. Table IV-4 differs in that it includes the direct water agency costs and the net customer costs. Others could rightfully argue that the true regional cost should include 1) the benefits of avoided capital investment in additional wastewater treatment facilities; 2) the benefit to homeowners of shifting saved water to outdoor use; 3) avoided energy costs; and 4) the benefit of avoided environmental degradation. If ULF toilet rebate programs appear attractive on narrowly defined cost-effectiveness grounds, we believe they will appear all the more attractive on broader grounds.

Table IV-4 Regional Cost Effectiveness: Estimated Cost per Acre Foot from ULF Toilet Replacement

Type of Toilet Replacement	Savings /Toilet (gpd) [1]	Savings /Toilet (AF/yr) [2]	Agency Cost ($) [3]	Customer Cost ($) [4]	Regional Cost ($) [5]	Regional Cost of Saved Water ($/AF) [6]
Single Family	21.6	0.024	$125	$80	$205	$489.83
Multiple Family	40.3	0.045	$125	$50	$175	$224.12
Commercial	73.6[§]	0.082	$125	$150	$275	$192.84
Low Income CBO	45.1	0.051	$125	$50	$175	$200.31

Notes:
[1] Water Saved per ULF toilet replacement in gallons per day (gpd).
[2] = [1] x 365 days ÷ 325,900 gallons per acre foot.
[3] Direct Water Agency Costs per ULF Toilet, Table IV-2.
[4] Net Customer Costs per ULF Toilet, Table IV-3.
[5] = [3] + [4].
[6] = [6] ÷ ([2] x 17.3 economic years), Assumes 1.4 percent net discount rate.
[§]This estimated level of savings should be considered provisional and reflective only of the sample of commercial accounts examined in this report.

V. CONCLUSIONS

This report documents the net water savings achieved by ultra low flush toilet rebate programs undertaken in the cities of Los Angeles and Santa Monica. Households participating in these programs saved significant additional amounts of water, even in the midst of an ongoing drought emergency. This report provides estimates of the mean savings per household and the amount of uncertainty surrounding these estimates. In addition, the water savings per retrofit vary in predictable ways. This knowledge can be used to improve the design of future ULF toilet rebate programs. Reducing the uncertainty surrounding the magnitude and character of the future benefit stream from ULF toilet replacement permits water planners and potential participants to more wisely invest water conservation. The findings of this report provide strong empirical support for the effectiveness of these conservation programs. ULF toilet replacement programs represent an important and cost-competitive alternative for meeting future water needs.

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REFERENCES

Bamezai, A. and T. W. Chesnutt (1994), Water Savings From Non-Residential Toilet Retrofits: An Evaluation of the City of San Diego's Public Facilities Retrofit Program, A report for the Metropolitan Water District of Southern California.

Chesnutt T.W. and C.N. McSpadden (1991), A Model-Based Evaluation of the Westchester Water Conservation Program, A report for the Metropolitan Water District of Southern California.

Chesnutt T.W., A. Bamezai and C.N. McSpadden (1992), Continuous-Time Error Components Models of Residential Water Demand, A report for the Metropolitan Water District of Southern California.

Chesnutt T.W., A. Bamezai and C.N. McSpadden (1992), Mapping the Conserving Effect of Ultra Low Flush Toilets: Implications for Planning, A report for the Metropolitan Water District of Southern California.

Chesnutt T.W., A. Bamezai and C.N. McSpadden (1992), The Conserving Effect of Ultra Low Flush Toilets, A report for the Metropolitan Water District of Southern California.

California Urban Water Conservation Council, Assumptions and Methodology for Determining Estimates of Reliable Water Savings from the Installation of ULF Toilets, Approved June 30, 1992.

Fuller, W. A., and Battese, G. E. (1974) "Estimation of Linear Models with Crossed-Error Structure," Journal of Econometrics, 2, 67-78.

Goldberger, A. S. (1968) "The Interpretation and Estimation of Cobb-Douglas Functions," Econometrica, 35, 464-472.

Hausman, J. A. (1978) "Specification Tests in Econometrics," Econometrica, 46, 1251- 1272.

Hausman, J. A. (1979) "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables: Comment," Bell Journal of Economics, 1, 33-54.

Henderson, C. R. (1953) "Estimation of Variance and Covariance Components," Biometrics, 9, 226-252.

Honda, Y. (1985) "Testing the Error Components Model with Non-Normal Disturbances,"Review of Economic Studies, LII, 681-690.

Taub, A. J. (1979) "Prediction in the Context of the Variance-Components Model," Journal of Econometrics, 10, 103-108.

APPENDIX A - RESIDENTIAL WATER DEMAND—DATA AND MODELS

The residential water demand model estimated to evaluate water savings ULF toilet rebate programs relates individual household water use to season, changes in climate, socioeconomic characteristics of the household, physical characteristics of the property, water-using behavior patterns, the price of water, and installation of water-saving conservation devices. The functional relationships among the above factors are estimated from historical household-specific water use data.

Models were re-estimated for both Los Angeles single family and multiple family rebate program participants. In addition, a set of parallel models was estimated for a random sample of accounts taken from the billing system. The models are based on billing histories from January 1986 through January 1990. Prior to January 1990, households were relatively unaffected by either the drought or the audit program.

Because we are interested in observing temporal changes in levels of conservation—seasonal patterns or developing trends—the magnitude and shape of water demand's response to changes in climate must be captured with accuracy. To estimate the impact of climate on water use as precisely as possible, we go to some lengths to ensure consistency between the specified model and the available data. Although water meters are read on a predetermined cycle (usually bi-monthly), the cycles do not represent the same calendar period for each household. Researchers in the past have avoided this problem by changing the structure of the data, either by aggregating water use to an annual level or by prorating water use data to a monthly level. Both techniques attenuate the "peaks" and "valleys" normally displayed by water use and thus wipe out important information that can be used in subsequent estimation of water demand.

To avoid this problem, we specify the conceptual household water use model at a daily level, not a bi-monthly level. By working with daily climate data, we construct an appropriate bi-monthly measure of climate that corresponds to the same calendar period that a household's meter reading represents. Geographic climatic differences are captured by working with four different weather stations for climatically different regions of the service areas.

The water demand model can capture separate effects for rainfall and temperature and it allows for these contemporaneous effects to vary through the year. (Temperature, for example, affects water demand differently in the winter than in the summer.) The water demand model can detect lagged effects of climate; rainfall two months ago may affect water demand today. The additional effort required to construct appropriate measures of climate from disaggregate daily data produces a detailed temporal representation of climate's effect on (metered) water demand.

The estimation methodology also explicitly accounts for the effects of unmeasured household characteristics. An example of such an unmeasured characteristic might be the water use behavior of household members. Omitting account specific effects, when they exist, can lead to severe specification bias[23]. Empirical tests strongly support inclusion of heterogenous intercepts in all customer classes in both single family and multiple family models[24]. This feature substantially increases forecast accuracy and the subsequent resolution of statistical inference.

Lastly, since the statistical analysis is predicated on metered water use, we gathered additional data on when a meter is repaired or retrofitted. Meter repairs or retrofits usually result in an increase in metered water consumption. Most utilities have meter repair and retrofit programs because meter sensitivity to water flow, especially low flow, declines with age. The City of Los Angeles maintains records on the last date each household has had a meter retrofit and provided this data to us. Information about meter repairs and retrofits, not surprisingly, turn out to be an important predictor of metered water use.

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[23]These statistical issues are more thoroughly discussed in Chesnutt T.W. and C.N. McSpadden (1991), A Model-Based Evaluation of the Westchester Water Conservation Program, A report for the Metropolitan Water District of Southern California.

[24]The null hypothesis that there are no household-specific error components was empirically tested using a one-sided Lagrangian Multiplier test as proposed by Honda (1985). The null hypothesis was rejected by this test at the 1 percent significance level. The specification of the household-specific effects as random was tested against the alternative of their being fixed using a Hausman (1978) test. The Hausman test does not reject the random specification of household-specific effects.

Model Structure

This section describes the structure of our general residential water demand model and its advantages compared to traditional models. The statistical methodology used to estimate the model is also discussed.

The water demand model is of the form:

$$\ln \boldsymbol{Q}_{it} = \boldsymbol{X}_{it}\beta + \epsilon_{it} \qquad (i=1,\ldots,N;\ t=1,\ldots,T) \tag{3}$$

where $\boldsymbol{Q}_{it}$ is the average daily water use of the i th account in the t th period. The explanatory variables $\boldsymbol{X}$ can be further divided:

$$\ln \boldsymbol{Q}_{it} = \boldsymbol{S}_t\beta_s + \boldsymbol{C}_{it}\beta_c + \boldsymbol{Z}_i\beta_z + \boldsymbol{P}_t\eta_p + \epsilon_{it} \tag{4}$$

The explanatory variables $\boldsymbol{X}$ include some which vary over time but not over accounts (seasonal effects, $\boldsymbol{S}_t$, and water rates, $\boldsymbol{P}_t$); some which vary over accounts but not over time (account characteristics, $\boldsymbol{Z}_i$); some which vary over both accounts and time (climatic effects, $\boldsymbol{C}_{it}$); and interactions between these variables (e.g., $\boldsymbol{Z}_i \cdot \boldsymbol{C}_{it}$). By including interactions one may allow accounts to respond differently to climate depending upon the season of the year or their account characteristics.

The error structure is assumed to be of the form:

$$\epsilon_{it} = \mu_i + \xi_{it} \tag{5}$$

where

$$\mu_i \sim (\ \mathbf{0}\ ,\ \sigma_\mu^2\ ) \tag{7}$$

$$\xi_i \sim (\ \mathbf{0}\ ,\ \sigma_\xi^2\ ) \tag{6}$$

The $\boldsymbol{X}$ and $\boldsymbol{\xi}$ are assumed to be independent of each other and of $\boldsymbol{\mu}$. The individual component $\boldsymbol{\mu}$ represents the effects of unmeasured household characteristics on household water use. An example of such an unmeasured characteristic might be the water use behavior of household members. This effect is assumed to persist over the estimation period. The second component $\boldsymbol{\xi}$ represents random error. Because $\boldsymbol{\mu}$ and $\boldsymbol{\xi}$ are independent, the error variance can be decomposed into two components:

$$\sigma_\epsilon^2 = \boldsymbol{T} \cdot \sigma_\mu^2 + \sigma_\xi^2 \tag{8}$$

This model specification is accordingly called an error components or variance components model.[25]

We estimate this model using the methods of Henderson (1953) and Fuller and Battese (1974). First, estimates for the two components of the error variance are derived from consistent residuals. In a form of estimated generalized least squares, the original data are then transformed using these consistent estimates of error parameters, thus producing an equation with a well-behaved error term. Least squares estimation in this transformed space produces unbiased and efficient estimates of the mean vector of parameters $\boldsymbol{\beta}$ and consistent estimates of its covariance matrix $\boldsymbol{\Sigma}$. This estimation is enacted using STATA© statistical software.

Specification of Continuous-Time Demand Functions

This section specifies the systematic form of the water demand functions. These models have several unique features. First, the theoretical form of the seasonal and climatic effects are a continuous function of time (as opposed to discrete monthly or bimonthly). By permitting the choice of an arbitrary discrete time index (days, weeks, months) a continuous time specification allows creation of a time-matched set of season and climate measures. Though this requires working with daily climate data, the precision of the demand function greatly increases through a precise time matching of water use and climate. Second, by using separate measures of climate for different geographical areas, additional spatial climatic variation enters into the models. Third, the models permit interactions of time-invariant account characteristics with the seasonal and climatic components. Thus, the climatic response of demand can be account specific. In other words, the models can determine whether, for example, households using automatic sprinkler systems respond differently to climate than households who water by hand.

[25]The null hypothesis that there are no household-specific error components was empirically tested using a one-sided Lagrangian Multiplier test as proposed by Honda (1985). The null hypothesis was rejected by this test at the 1 percent significance level. The specification of the household-specific effects as random was tested against the alternative of their being fixed using a Hausman (1978) test. The Hausman test does not reject the random specification of household-specific effects.

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Because household water use is measured on a continuous two-month cycle, our model of water demand uses explanatory variables that match the sixty-one day meter reading cycle. Thus, if a household's meter is read on October 15, the meter reading represents water use in the previous two months, approximately from August 15 to October 15. The associated explanatory variable of precipitation should also represent how much rain fell in this same period. We specify a continuous time form of a demand function that permits a consistent time matching.

A Fourier series defines the seasonal component of the model. For a given day T and a harmonic index j we define the following harmonics:

$$S\beta = \sum_{j=1}^{6}\left\{\beta_{1,j}\sin\left(\frac{2\pi jT}{365}\right) + \beta_{2,j}\cos\left(\frac{2\pi jT}{365}\right)\right\}$$
$$\text{,where} \quad T = (1,\ldots,365).$$

Next a moving average of each harmonic, corresponding to the length of the meter reading period, is taken to yield a corresponding measure of a constant seasonal component. Because the lower frequencies tend to explain most of the seasonal fluctuation, the higher frequencies can be omitted with little predictive loss.

The models incorporate two types of climate measures: air temperature and rainfall. We use the average maximum daily temperature and the total amount of rainfall in the 61-day meter reading cycle[26]. The 61-day measures of temperature and rainfall are then logarithmically transformed to yield:

$$\ln\left\{1 + \sum_{t=T}^{T-61} Rain_t\right\} \quad , \quad \ln\left\{\sum_{t=T}^{T-61} Temp_t\right\} \tag{10}$$

These measures of climate in a 61-day period can be reexpressed as a historic mean and departure from historic (geometric) mean. The historical geometric

[26]Our climate measures are constructed from daily rainfall and temperature readings taken at NOAA weather stations in four geographical zones: Santa Monica, Los Angeles Civic Center, Canoga Park, and Long Beach. Climate data from the Santa Monica weather station is used for households located in both Santa Monica and West Los Angeles; Los Angeles Civic Center weather station for households in Los Angeles County; Canoga Park weather station for households in the San Fernando Valley; and the Long Beach weather station for households in the San Pedro area.

mean applicable for a given 61-day billing period is based on the average of climate that prevailed during similar 61-day periods from 1948 to 1990. Subtracting the (geometric) mean, we express climatic deviations as:

$$R_t\beta_R \equiv \ln\left\{1 + \sum_{t=T}^{T+61} Rain_t\right\} - \overline{\ln\left\{1 + \sum_{t=T}^{T+61} Rain_t\right\}}\ ,$$

$$T_t\beta_T \equiv \ln\left\{\sum_{t=T}^{T+61} Temp_t\right\} - \overline{\ln\left\{\sum_{t=T}^{T+61} Temp_t\right\}}\ \text{,and}$$

$$C_t\beta_c \equiv R_t\beta_R + T_t\beta_T$$

By constructing the climatic measures in this deviation-from-mean form, they are made independent of the seasonal effect. (If the means were not subtracted, there would be a strong correlation between season and climate.) Thus, the constant seasonal component of the model captures all constant effects including normal climate effects.

In processing the billing histories, we encountered "estimated" meter readings. Estimates of meter readings are made when the meter reader does not have direct physical access to the meter. The estimate itself is a guess that, however reasonable, does not convey any information about actual water use in that billing period. In the following meter reading cycle, an "adjusted" read is made so that the cumulative meter reading is accurate. By combining the "estimated" meter read with the following "adjusted" meter read, one obtains the cumulative amount of water used over both meter read periods. For such combined readings, the climate and seasonal variables were also calculated on a 121-day basis instead of the 61-day basis described above. Thus, great care was taken to preserve as much water use history as possible without tampering with the climate and seasonal patterns implicit in these data.

The model specifies a richer texture in the temporal effect of climate than the usual fixed contemporaneous effect. The temporal specification of climate allows for the contemporaneous effects to vary though the season[27]. In addition, the model allows for lagged effects of rainfall, so that the effect of rainfall two months prior to a billing period can be estimated.

Forecasting Water Demand Using Error Components Models

The error component water demand models yield an estimate of how a given household departs from the systematic prediction of the model. This household-specific calibration factor, μ_i captures the total effect of all unmeasured characteristics for that household. Our estimator of the household-specific factors is given by[28]:

$$\hat{\mu}_i = \left(\frac{\sigma_\mu^2}{\sigma_\epsilon^2} \right) i_t'(USE_i - X_i\hat{\beta}) \tag{12}$$

Combining the estimated random effect with the forecast from the systematic portion of the water demand model (i.e., $X\beta$) produces substantially more accurate household-specific forecasts than forecasts from models that do not estimate and use these calibration factors. Since the accuracy of water savings that result from audit programs greatly depends on the accuracy of estimated total conservation for each household, we believe the use of error components models can be justified on both practical and theoretical grounds. In short, selection of a simpler statistical model would compromise the accuracy of estimated household conservation.

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[27]We allow for seasonality in the climatic effects by interacting the climatic measures with the harmonic terms. The same effect could be achieved, at some loss in model parsimony, by interacting climate with seasonal dummy variables.

[28]Taub (1979) proposed this as the best linear unbiased predictor of μ_i and discusses prediction from this type of model.

Data For Estimating Water Demand Models

Our evaluation of ULF toilet rebate programs used data from approximately 2,900 single family households and 2,900 multiple family complexes (representing approximately 27,000 multiple family units) that participated in the program over the last three years. In addition, we obtained a random sample from the billing system of another approximately 2500 nonparticipating single family accounts and 2200 nonparticipating multiple family accounts. Many households that participated in the toilet rebate program could not be included in this detailed evaluation because critical data were incomplete or inconsistent. In addition, in many cases adequately long billing histories were unavailable because families had only recently moved into their current residences.

Table A-1 and A-2 describes the basic demographic and property characteristics of the participating households that were used for estimating models of residential water demand. Some data cleaning had to be undertaken because occasionally we encountered responses that were either unrealistic or incomplete. In cases where households left some questions unanswered, we created categorical variables to indicate the type of missing information. For example, many households did not know the amount of turf area their homes had, but admitted indirectly to having a lawn by either stating that they had a sprinkler system or that they were watering by hand. Rather than hazard guesses about the size of their lawns or whether they truly had a sprinkler or not, we created categorical variables to distinguish such households from the rest.

Table A-1: Characteristics of Single Family Households in Los Angeles

CHARACTERISTICS	LOS ANGELES
Mean number of people per household	2.85
Mean number of toilets per household	2.06
Mean number of ULF toilets replaced per household	1.50
Proportion of pre-existing toilets thought to be 3.5 gpf	0.20
Mean number of showerheads per household	1.75
Mean number of lowflow showerheads per household	1.51
Proportion of households with washing machines	0.95
Proportion of households with lawns	0.89
Proportion of households that reported turf area information	0.76
Mean turf area among reporting households (square feet)	1843
Proportion of households with a sprinkler irrigation system	0.65
Proportion of households with an automatic sprinkler irrigation system	0.31
Proportion of households with a pool	0.24
Proportion of households with a spa or tub	0.16
Mean water use per household (gpd) in estimation period	445

Table A-2 Characteristics of Multiple Family Complexes in Los Angeles

CHARACTERISTICS	LOS ANGELES
Mean number of people per unit	2.58
Mean number of toilets per unit	1.17
Mean number of ULF toilets replaced per unit	.98
Proportion of Replaced toilets thought to be 3.5 gpf	.14
Mean number of showerheads per unit	1.09
Mean number of Low Flow Showerheads per unit	1.04
Proportion of complexes with washing machines	0.74
Proportion of complexes that reported turf area information	0.57
Mean turf area among reporting complexes (square feet)	970.
Proportion of complexes with a sprinkler irrigation system	0.30
Proportion of complexes with an automatic sprinkler irrigation system	0.10
Proportion of complexes that reported watering lawn regularly	0.18
Proportion of complexes that reported watering lawn periodically	0.24
Proportion of complexes that reported watering lawn rarely	0.23
Proportion of complexes with a pool	0.09
Proportion of complexes having meters replaced	.32
Mean water use per unit in estimation period (gallons per unit per day)	226.
Mean number of units per complex	9.5

Sample Weights

Detailed customer characteristics were available for only program participants, not the entire customer base. Thus, a comprehensive examination of the question, "Are program participants different?" was not feasible. However, LADWP's billing system contains information about every customer's location, meter size, and in the case of multifamily complexes, number of units. We were thus able to compare participants to the entire population of customers at least on these characteristics. Only mild differences were found. A set of post-stratification sample weights, based upon universally available characteristics from the billing system, were used to correct for imbalance between the sample and the service area. For single family accounts, three categories of meter size and the four geographical districts were used to arrive at (3x4) 12 cells. For multiple family complexes, five categories of complex size (less than five to nine units, 10 to 24 units, 25 to 49 units, and 50 or more units) and three geographical zones (the West Los Angeles and Harbor Districts were combined) were used to give 15 cells. Sampling weights were derived as the ratio of the proportion of customers with a given set of characteristics in the population over the proportion in the participant group. The data were weighted prior to estimation to yield models that represent the service area. The post-stratification weights were also retained to test for the effect of imbalance on estimates of net conservation in the post-estimation period.

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Estimated Residential Water Demand Models

Table A-3 and A-4 present the estimated water demand models for single family households and multiple family units. The models are estimated on water use histories prior to January 1990, the pre-drought and pre-program period. The estimated models are reduced form demand models whose primary purpose is forecasting. However, the estimated coefficients reveal important information about the role of the different factors that affect household water demand.

Table A-3: Los Angeles Single Family Residential Water Demand Model

VARIABLE DEFINITION	Coefficient	Standard Error	t-Statistic
	ß	σ	ß/σ
Mean Intercept	4.6309	0.099	46.945
ln(marginal price of water + sewer disposal)	-0.0462	0.030	-1.543
ln(marginal price)*Indicator for 0<irrigated area≤1500 sq. ft.	-0.0361	0.033	-1.101
ln(marginal price)*Indicator for 1500<irrigated area≤3000 sq. ft.	-0.0590	0.033	-1.787
ln(marginal price)*Indicator for 3000<irrigated area≤5000 sq. ft.	-0.0816	0.034	-2.424
ln(marginal price)*Indicator for 5000<irrigated area≤10,000sq.ft.	-0.0921	0.035	-2.640
ln(marginal price)*Indicator for irrigated area > 10,000 sq. ft.	-0.1101	0.043	-2.568
Indicator(=1) when meter was replaced	0.0761	0.008	9.618
Number of Low Flow Showerheads installed	-0.0120	0.004	-3.209
First Sine harmonic, 12 month (annual) frequency	-0.1103	0.003	-35.449
First Cosine harmonic, 12 month (annual) frequency	-0.2957	0.003	-106.853
Second Sine harmonic, 6 month (semiannual) frequency	-0.0059	0.002	-2.647
Second Cosine harmonic, 6 month (semiannual) frequency	0.0025	0.002	1.074
Third Cosine harmonic, 4 month frequency	0.0205	0.003	7.771
Fifth Cosine harmonic	-0.0795	0.009	-9.261
First Sine harmonic * S. F. Valley Indicator	-0.0727	0.004	-16.929
First Cosine harmonic * S. F. Valley Indicator	-0.1003	0.004	-24.623
Deviation of *ln*(1+rain) from its bimonthly mean	-0.0749	0.004	-18.440
Two month lag of Rainfall Deviation	-0.0322	0.003	-12.665
Deviation of *ln*(temperature) from its bimonthly mean	0.7757	0.067	11.563
Deviation of *ln*(1+rain) * S. F. Valley Indicator	0.0228	0.005	4.482
Deviation of *ln*(temperature) * S. F. Valley Indicator	0.9860	0.084	11.804
Rainfall * First Sine Harmonic	-0.0237	0.005	-5.054

VARIABLE DEFINITION	Coefficient	Standard Error	t-Statistic
	ß	σ	ß/σ
Rainfall * First Cosine Harmonic	-0.0143	0.007	-1.951
Temperature * First Sine Harmonic	0.2191	0.062	3.517
Temperature * First Cosine Harmonic	0.0818	0.066	1.247
Rainfall * First Sine Harmonic * S. F. Valley Indicator	0.0097	0.006	1.634
Rainfall * First Cosine Harmonic * S. F. Valley Indicator	-0.0290	0.010	-3.048
Indicator(=1) if household has a pool	0.3203	0.018	17.478
Indicator(=1) if household has a washer	0.1198	0.047	2.528
ln (Number of laundry loads washed per week)	0.0964	0.013	7.254
Indicator(=1) information about number of laundry loads is missing	0.2835	0.072	3.925
ln (turf area in square feet)	0.0155	0.005	3.156
Indicator if Household has a sprinkler system	0.2007	0.021	9.405
Indicator if Household has an automatic sprinkler with timer	0.1679	0.020	8.391
Temperature * automatic sprinkler indicator	-0.1630	0.075	-2.182
Indicator(=1) if turf area information is missing but household reports having a sprinkler system	0.6095	0.146	4.167
Indicator(=1) if turf area information is missing but household reports not having a sprinkler system	0.1087	0.151	0.720
ln (Individuals per household)	0.2345	0.018	13.079

Dependent variable	:	*ln*(Gallons per household per day)
Observations	:	58030
Number of Groups	:	2944
Standard error of white noise error	:	0.279
Standard error of Individual constant terms	:	0.413
Intracluster Correlation	:	0.850
F	:	9169.475
R-Square	:	0.832

Table A-4 Los Angeles Multiple Family Residential Water Demand Model

VARIABLE DEFINITION	COEFFI-CIENT	STANDARD ERROR	t-STATISTIC
	ß	σ	ß/σ
Mean Intercept	4.699	.077	60.812
ln (People per unit)	.415	.021	19.772
ln (Teenagers and Children per unit)	.081	.009	8.368
ln (Number of units in complex)	-.469	.017	-26.216
Indicator(=1) if complex has a washer	.054	.017	3.170
Indicator(=1) if complex has a pool	.056	.023	2.372
Indicator(=1) when meter was replaced	.106	.006	16.511
NoLawn*First Sine harmonic	-.037	.003	-11.869
NoLawn*First Cosine harmonic	-.044	.002	-15.138
NoLawn*Second Sine harmonic	.008	.003	2.414
NoLawn*Deviation of *ln*(temperature)	.252	.064	3.922
Lawn*First Sine harmonic, 12 month (annual) frequency	-.051	.003	-16.863
Lawn*First Cosine harmonic, 12 month frequency	-.095	.002	-34.302
Lawn*Second Sine harmonic, 6 month frequency	.011	.002	3.992
Lawn*Third Sine harmonic, 4 month frequency	.006	.003	1.719
S.F.Valley*Lawn*First Sine harmonic	-.021	.005	-3.871
S.F.Valley*Lawn*First Cosine harmonic	.003	.005	0.569
Lawn*Deviation of *ln*(temperature)	.348	.055	6.285
Lawn*Deviation of *ln*(1+rain) from its bimonthly mean	-.022	.003	-5.735
Lawn*Two month lag of Rainfall Deviation	-.020	.003	-5.454
ln(turf area) * Water by Hand Indicator(=1)	.021	.009	2.232
ln(turf area) * Automatic Sprinkler * Water Rarely	0.15	.010	1.491
ln(turf area) * Automatic Sprinkler * Water Periodically	.024	.009	2.607
ln(turf area) * Automatic Sprinkler * Water Regularly	.030	.009	3.215
NoLawn**ln*(marginal price of water + sewer disposal)	-.042	.016	-2.576

VARIABLE DEFINITION	COEFFI-CIENT	STANDARD ERROR	t-STATISTIC
	ß	σ	ß/σ
Lawn**ln*(marginal price of water + sewer disposal)	-.133	.015	-8.747

(continued)

Table A.4 (continued)

Dependent variable	:	*ln*(Gallons per unit per day)
Observations	:	56052
Number of Groups	:	2301
Standard error of white noise error	:	0.301
Standard error of individual constant terms	:	0.335
Intracluster Correlation	:	0.821
F	:	2551.150
R-Square	:	0.7180

The Effect of Marginal Price on Household Water Demand

Los Angeles assesses sewer charges directly based on water consumption. Thus, the actual marginal price of water that a consumer faces in Los Angeles is the sum of both the direct price of water and price of sewer service. Figure A-1 shows how the nominal and real price of water and sewer disposal has varied since 1984 in Los Angeles.

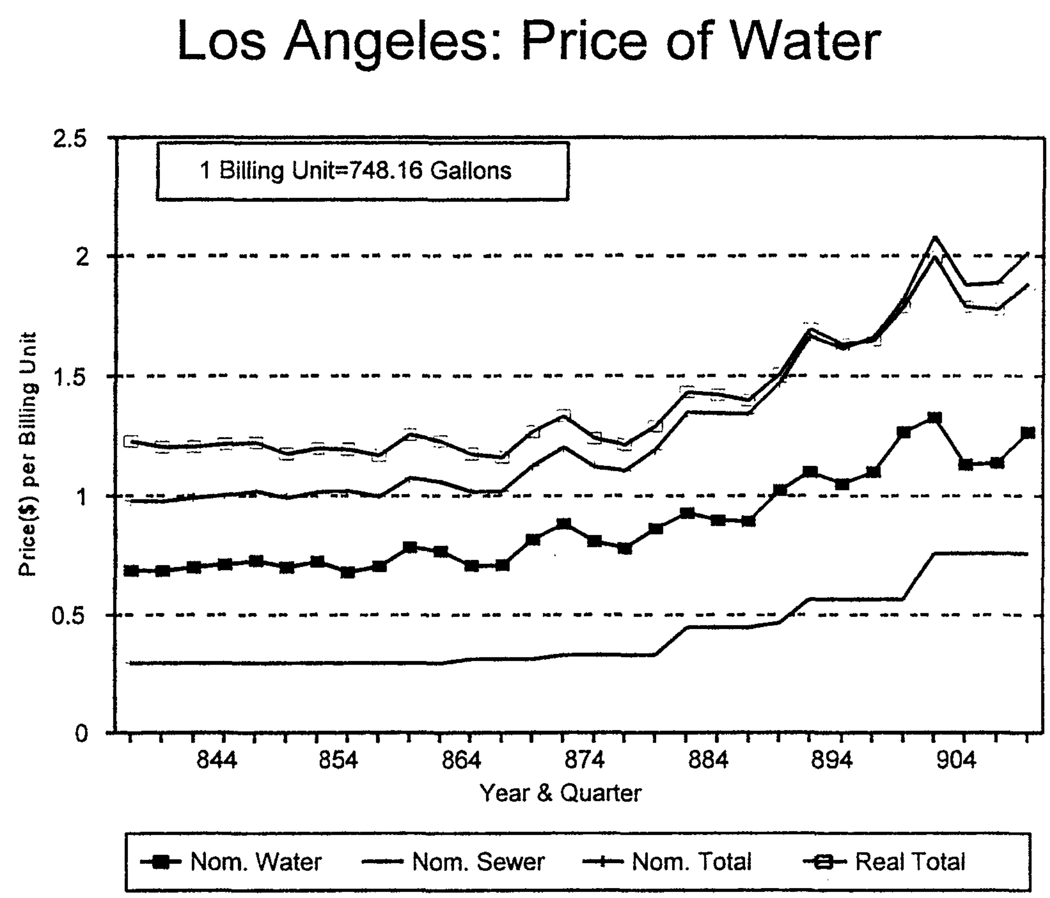

Figure A-1: Los Angeles: Price of Water and Sewer Disposal (Nominal and Real 1990 Dollars)

Caution should be used in interpreting the estimated price elasticities. The models of individual household water demand control for decreases in water use attributable to the retrofit of water saving devices, such as low-flow showerheads. Our estimated price elasticity explicitly excludes reduction of water use through device retrofit, even if the retrofits are price motivated. As such, the estimated price elasticity is a measure of short-run behavioral response. Further, it is only valid for the range of price variability seen in the historical sample.

Given these qualifications, the following interpretation can be placed on the estimated response to price. The response to price depends on the existence and amount of outdoor water use. All single family households begin with an indoor price elasticity of -4.6 percent. Roughly speaking, this means that a 10 percent increase in price would reduce water demand by about half of one percent. (The existence of a substantial number of single family households that have no irrigated area permits the estimate of this coefficient.) The total price response for single family households that do have irrigated area is greater and depends on the amount of irrigated area. For example, the estimated coefficient for homes having 1500 square feet or less of irrigated area is -3.6 percent, giving a total price response (indoor plus outdoor) of 8.2 percent (=.046+.036).

Figure A-2 graphically illustrates the interpretation of the estimated price response for single family homes[29].

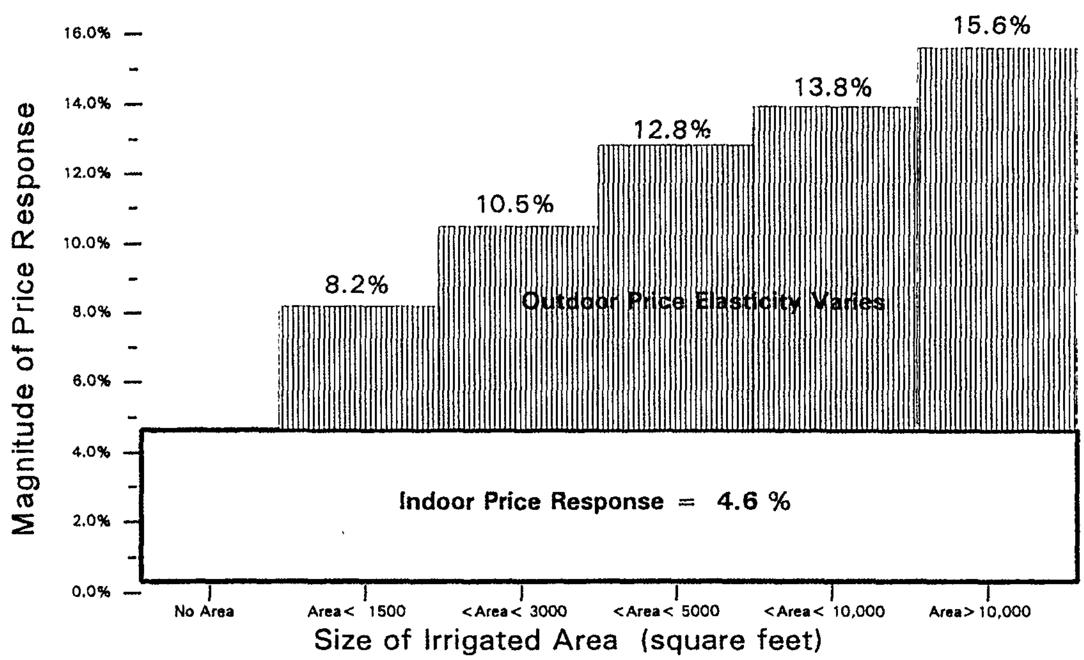

Figure A-2: Single Family Households Estimated Price Elasticities

[29]The average price elasticity, across all households in the sample, is about -0.09.

D-045766

For multiple family complexes in Los Angeles, the pure behavioral response to price also depends on the existence of outdoor water uses. Complexes with no significant outdoor water use exhibit a price response of about 4 percent. Complexes that have outdoor water use exhibit a stronger response to price, about 13 percent—a 10 percent increase in price would reduce water demand by about 1.3 percent.

However, the price elasticities that we estimate should be considered relevant only as a measure of the short term response to price. Most of the price variation in Los Angeles occurred only toward the latter part of the time period on which our model estimates are based. Moreover, if prices were to increase significantly in the future, many households might find it profitable to retrofit their homes with water conservation devices without any stimulation from water utilities. Therefore, long term responses to price can be significantly greater than the price elasticity estimates presented here.

Meter Replacement: Most utilities have meter repair and retrofit programs that primarily aim at ensuring equity in water billing. Meter replacement programs can also be thought of as conservation programs because they reduce unaccounted for water use and increase the accuracy of the price signal being given to customers. Evaluations of conservation programs that are based upon metered water consumption are sensitive to any changes made to water meters during the evaluation time period. Due to wear and tear, water meters become less sensitive to water flow. As a result, they under-register water consumption. The measured increase in metered water consumption after a meter retrofit could decrease the apparent effect of a water conservation program, unless the retrofit is explicitly accounted for in the analysis.

As the demand model shows, metered water consumption in single family homes increased by 7.9 percent after a meter was retrofitted[30]. Measured water use

[30]This calculation is more complicated than it might appear at first. The estimated coefficient on the meter retrofit indicator variable gives the conditional median percentage change, not the conditional mean percentage change. A small scaling adjustment (see Goldberger, 1968) must be made to arrive at the correct expected

per multiple family unit increased by 10.8 percent upon meter replacement. Thus the impact of meter retrofit is large and cannot be ignored.

<u>Indoor Characteristics</u>: Factors that explain indoor water use (such as the number of residents, the number of pre-existing low flow shower-heads, whether a household has a laundry machine, and laundry washing behavior) are, not surprisingly, strong predictors of total household water demand. Each low flow showerhead reduces household use by about 1.2 percent. At a sample mean water use of 445 gallons per day, this translates into about 5.34 gallons per showerhead. This is an independent estimate of the effect of low flow showerheads in the estimation period comes very close to the estimate produced by the mapping model in the next appendix. Households with laundry machines used and 12.6 percent (= $\exp[0.12-.047^2/2] - 1$; see previous footnote) more water and an additional amount that depends on the number of loads of laundry. Because we had no measure for the presence of dishwashers in a home, the estimated coefficients for laundry machines are likely to represent some nonlaundry water use. Households having more residents tended to use more water.

<u>Outdoor Characteristics</u>: Outdoor amenities such as a pool, turf area, and irrigation system all strongly influence household water demand. The multiple family models have separate coefficients estimated for complexes that have significant outdoor water use. Single family household water demand also depends strongly on how water is used outside. A household with a pool on average consumed 37.8 percent more water compared to other similar households without a pool. This should not be interpreted causally—i.e., installation of a pool would cause household water use to increase 38 percent due to the initial filling and subsequent replacement of evaporation losses. A problem that plagues end-use interpretation of regression models is that the presence of water-using equipment may be correlated with other

---

percent change of water use: $(\exp(\beta - \sigma^2/2) - 1)*100$. Thus, the expected percent increase in water consumption from having a meter retrofitted is $(\exp(0.076 - (0.008^2/2)) - 1)*100 =$ 7.89 percent. Based upon the average pre-drought water consumption of 445 gallons per household per day, this works out to a mean increase of 35.1 gallons per household per day.

forces that drive a households water use. The presence of a pool at a single family residence is very likely to be indicative of a higher-income household that may possess different water using habits or equipment.

Turf area and the type of irrigation system also appears to be a strong predictor of household water demand. Because turf area information was either missing or incomplete in many cases, we insert indicator variables to capture the net effect of the missing information. Thus, the parameter on the impact of turf area and irrigation system type is estimated only for those households that had complete information. Households with in-ground irrigation systems and no automatic timer use about 22 percent more water than households that reported watering with a hose. Households having both an in-ground irrigation system and an automatic timer use about 18 percent more than households that water by hand In addition, these same households exhibit less sensitivity to changes in climate--increases or decreases of temperature from normal levels produces a proportionally smaller response.

Climate and Season: Demand for water normally follows a cyclical pattern during the course of a year because of changes in climate. Perturbations are produced in these cyclical patterns when climate conditions deviate from their normal values for a given time of year. We estimate both of these effects (i.e., normal climate and deviation from normal) separately in our models. The seasonal harmonics included in the demand models represent variation in water demand through the seasons that would be expected in any normal year. We also include variables that represent deviation of actual rainfall and temperature from their normal values to capture the response of water demand to deviations in climate. Lastly, since the effect of deviation from normal climate may have different impacts on water demand at different times of the year, we include interactions between the harmonics and climate deviation variables.

As the water demand model shows, normal variation in water use over the course of a calendar year is complex and therefore necessitates the inclusion of a large number of harmonics in the model. As expected, greater than normal rainfall dampens demand for water while greater than normal temperature increases demand for water. Greater than normal rainfall reduces demand not only in the bimonthly period in which it occurs, but also in the following bi-monthly period. For example, a 1 percent greater than normal rainfall reduces water demand by 0.075 percent in the contemporaneous period and 0.032 percent in the following period. The model also shows that response of water demand to deviations in climate is not constant but varies by time of year.

The response of water demand to climate also varies among households depending their location in the LADWP service area. Since households in the San Fernando Valley have larger turf areas and the climate is also hotter, the response to climate is accordingly steeper. Multiple family complexes exhibit, overall, much less seasonality of use and a smaller response to climatic fluctuations.

Appendix B: Models to Describe and Map Conservation

This appendix contains a set of statistical models that describe and explain ("map") the estimated conservation among residential ULF rebate program participants. Since, conservation mappings we develop build upon the analysis of variance (ANOVA) approach taken to estimate the net conservation of participants, we discuss the simple descriptive statistics of estimating mean conservation.

Mean Net Conservation Among Participants

We formally express the ANOVA model as:

$$\begin{array}{l} \textit{Model Estimated} \\ \textit{Conservation per Household} \\ (\textit{Expected Use} - \textit{Actual Use}) \end{array} \equiv \mathbf{C} = \alpha_i + \mu_{P,i} \cdot \textbf{\textit{Participation}}_i + \epsilon_i \qquad (13)$$

where $i = 1,2,\ldots,6$ (*bimonthly index*)
and $\epsilon_i \sim \mathbf{N}(\mathbf{0}, \sigma_i^2)$

The α are constant terms, one for each period, representing ongoing conservation among nonparticipants. The variable ***Participation*** is a zero-one indicator for a household's participation in the ULF toilet rebate program. By construction, the parameter $\mu_{P,i}$ represents the mean net conservation of participants in time period i. The error term ϵ_i is allowed to have a different dispersion in each period. Tables B-1 and B-2 present the ANOVA estimates of net conservation for single family and multiple family participants.

Table B-1: Single Family Conservation per Household - Descriptive Model

Variable Name	Coefficient	Standard Error	t-Statistic	Count
Indicator (=1) if meter was read in May or June 1990	48.353	2.596	18.626	2731
Indicator (=1) if meter was read in July or August 1990	78.559	3.174	24.751	2632
Indicator (=1) if meter was read in September or October 1990	58.773	3.287	17.881	2387
Indicator (=1) if meter was read in November of December 1990	20.645	3.197	6.459	2087
Indicator (=1) if meter was read in January or February 1991	5.716	2.714	2.106	2033
Indicator (=1) if meter was read in March or April 1991	50.727	2.513	20.186	1847
Indicator (=1) if meter was read in May or June 1991	108.947	3.16	34.478	1539
Indicator (=1) if meter was read in July or August 1991	136.605	4.325	31.583	1250
Indicator (=1) if meter was read in September or October 1991	135.434	5.826	23.245	601
Indicator (=1) if meter was read in November or December 1991	86.512	5.976	14.476	476
Indicator (=1) if meter was read in January or February 1992	29.878	4.96	6.024	509
Indicator (=1) if meter was read in March or April 1992	44.239	3.835	11.535	566
Indicator (=1) if meter was read in May or June 1992	68.373	4.725	14.471	553
Indicator (=1) if meter was read in July or August 1992	82.323	6.603	12.468	566
Estimated Net Effect of Participation				
Participant Indicator* (=1) if meter was read in May or June 1990	24.916	7.119	3.5	195
Participant Indicator* (=1) if meter was read in July or August 1990	35.945	7.369	4.878	380
Participant Indicator* (=1) if meter was read in September or October 1990	42.805	6.485	6.601	514

Variable Name	Coefficient	Standard Error	t-Statistic	Count
Participant Indicator* (=1) if meter was read in November of December 1990	55.442	5.711	9.709	603
Participant Indicator* (=1) if meter was read in January or February 1991	52.033	4.209	12.363	700
Participant Indicator* (=1) if meter was read in March or April 1991	31.019	3.904	7.945	991
Participant Indicator* (=1) if meter was read in May or June 1991	32.114	4.436	7.24	1289
Participant Indicator* (=1) if meter was read in July or August 1991	50.159	5.387	9.311	1673
Participant Indicator* (=1) if meter was read in September or October 1991	41.24	6.656	6.196	2236
Participant Indicator* (=1) if meter was read in November or December 1991	42.285	6.494	6.511	2042
Participant Indicator* (=1) if meter was read in January or February 1992	44.139	5.359	8.237	2105
Participant Indicator* (=1) if meter was read in March or April 1992	40.791	4.292	9.503	2302
Participant Indicator* (=1) if meter was read in May or June 1992	41.934	5.345	7.846	2294
Participant Indicator* (=1) if meter was read in July or August 1992	43.402	7.944	5.463	1202

Dependent variable : Model Estimated Conservation (gpd per household)
Observations : 38303
R-Square : 0.3887

D-045773

Table B-2: Multiple Family Conservation per Unit — Descriptive Model

Variable Name	Coefficient	Standard Error	t-Statistic	Count
Indicator (=1) if meter was read in May or June 1990	19.442	1.131	17.184	3017
Indicator (=1) if meter was read in July or August 1990	21.842	0.984	22.205	5354
Indicator (=1) if meter was read in September or October 1990	20.553	1.026	20.038	4955
Indicator (=1) if meter was read in November of December 1990	12.823	1.063	12.059	4497
Indicator (=1) if meter was read in January or February 1991	10.599	1.056	10.035	4355
Indicator (=1) if meter was read in March or April 1991	23.991	1.05	22.86	4220
Indicator (=1) if meter was read in May or June 1991	36.706	1.095	33.508	3761
Indicator (=1) if meter was read in July or August 1991	47.19	1.218	38.755	3514
Indicator (=1) if meter was read in September or October 1991	45.018	1.42	31.698	2843
Indicator (=1) if meter was read in November or December 1991	43.151	1.524	28.322	2439
Indicator (=1) if meter was read in January or February 1992	31.101	1.408	22.084	2499
Indicator (=1) if meter was read in March or April 1992	30.385	1.343	22.629	2777
Indicator (=1) if meter was read in May or June 1992	33.652	1.402	24.01	2750
Indicator (=1) if meter was read in July or August 1992	31.952	2.289	13.96	1175
Indicator (=1) if household lives in Santa Monica	-13.413	0.914	-14.681	
Indicator (=1) if household lives in W. Los Angeles or Harbor District	-7.072	0.725	-9.756	
Indicator (=1) if household lives in San Fernando District	-7.08	0.616	-11.484	

Variable Name	Coefficient	Standard Error	t-Statistic	Count
Participant Indicator (=1) if meter was read in May or June 1990	20.864	4.593	4.543	196
Participant Indicator (=1) if meter was read in July or August 1990	34.287	4.093	8.377	314
Participant Indicator (=1) if meter was read in September or October 1990	38.104	3.452	11.038	483
Participant Indicator (=1) if meter was read in November of December 1990	39.861	3.144	12.68	589
Participant Indicator (=1) if meter was read in January or February 1991	41.156	2.742	15.008	743
Participant Indicator (=1) if meter was read in March or April 1991	31.877	2.091	15.243	1242
Participant Indicator (=1) if meter was read in May or June 1991	40.089	1.824	21.973	1707
Participant Indicator (=1) if meter was read in July or August 1991	44.236	1.818	24.339	2120
Participant Indicator (=1) if meter was read in September or October 1991	40.37	1.853	21.791	2790
Participant Indicator (=1) if meter was read in November or December 1991	45.701	1.997	22.879	2310
Participant Indicator (=1) if meter was read in January or February 1992	51.87	1.841	28.174	2355
Participant Indicator (=1) if meter was read in March or April 1992	49.972	1.749	28.577	2679
Participant Indicator (=1) if meter was read in May or June 1992	48.742	1.83	26.635	2628
Participant Indicator (=1) if meter was read in July or August 1992	53.538	2.894	18.497	149

Dependent variable : Model Estimated Conservation (gpd per unit)
Observations : 69807
R-Square : 0.3543

D-045775

Conservation Mappings

Instead of estimating the overall mean difference between participants and nonparticipants, we can respecify the model to include measures of anything thought to make conservation vary—the number of toilets retrofitted (**T**), the number of showerheads retrofitted (**S**), the number of people per household (**P**), or other household characteristics.

For comparison we examine the functional specification implied by the commonly used mechanical/engineering estimates—multiply the number of flushes per household by how much less water is used with each flush:

$$
\begin{aligned}
& C = \bar{\Delta} \cdot F \cdot T \\
\text{where } & \bar{\Delta} \equiv \text{Mean Gallons per Flush Savings,} \\
& F \equiv \frac{P \cdot \bar{f}}{T} \text{ ;Mean Flushes per Toilet per Day,} \\
\text{and } & \bar{f} \equiv \text{Mean Flushes per Person per Day}
\end{aligned}
\qquad (14)
$$

The mechanical estimate implies a conservation mapping that is a simple linear function of the number of people in the household ($C = \Delta f \bullet P$) as long as all toilets are retrofitted[31]. Graphically, this conservation mapping takes the form of a straight line[32], going through the origin and having a constant slope equal to Δf. Whether or not the assumption of linearity implicit in the mechanical conservation mapping is true, is of course empirically testable. We perform this test and show that the linearity implied by the mechanical method is not supported by the data.

We specify a more general form for the conservation mapping that explicitly allows total conservation in a household to vary nonlinearly with the number of retrofitted toilets and the number of people in the household. We also include a measure to control for the mean effect of low-flow showerhead retrofits.

---

[31] An assumption of proportionality is generally used to accommodate for less than complete retrofit: $C = \Delta \bullet f \bullet P \bullet PenetrationRate$.

[32] The constant slope property of the mechanical estimate translates into a constant per capita effect of toilet retrofit. This is an attractive property in that it yields a simple calculation for estimating savings: multiply the number of people by the per capita effect. The per capita effect contains all of the information of the mechanical estimate.

The conservation mapping we specify has the following form:

$$C = \alpha_i + \beta_S \cdot S + \beta_T \cdot T + \beta_{T^2} \cdot (T^2; T>1) + \beta_{TP} \cdot (TP) + \beta_{T^2P^2} \cdot (T^2P^2) + \epsilon_i$$

where $i = 1,2,\ldots,6$ (*bimonthly index*) **(15)**
and $\epsilon_i \sim \mathbf{N}(0, \sigma_i^2)$

The $\boldsymbol{\beta}$ coefficients have the following interpretation. The coefficient on the number of low-flow showerheads, $\boldsymbol{\beta_S}$, represents the increase in household conservation resulting from each low-flow showerhead retrofit. We expect this parameter to take on a positive sign ($\mathbf{E}[\boldsymbol{\beta_S}] > 0$). Retrofitting a toilet has a constant effect, $\boldsymbol{\beta_T}$ and an effect that depends on the number of toilets (greater than one) being retrofitted $\boldsymbol{\beta_{T^2}}$. We may test for linearity in the per toilet effect by testing to see if the parameter $\boldsymbol{\beta_{T^2}}$ is distinguishable from zero. If the per toilet effect declines with the number of toilets, $\boldsymbol{\beta_{T^2}}$ will take on a negative value($\mathbf{E}[\boldsymbol{\beta_{T^2}}] < 0$). The effect of a toilet retrofit will also depend on the number of people using the toilet. Thus we expect the parameter on the interaction of toilets and people $\boldsymbol{\beta_{TP}}$ to take on a positive value ($\mathbf{E}[\boldsymbol{\beta_{TP}}] > 0$); the more people using the toilet, the greater the conservation. Linearity in this effect can be tested by seeing if the parameter $\boldsymbol{\beta_{T^2P^2}}$ is distinguishable from zero. If this parameter takes on a negative sign, this implies a declining per capita effect of toilet retrofit.

This conservation mapping provides a relatively simple functional form that is still general enough to capture the variation in conservation among households. We also estimated alternative conservation mappings using additional household characteristics but found that these additions purchased little in the way of either increased explanation or precision, especially after allowing for declining marginal returns from additional retrofits (i.e., the declining effects captured by the parameters $\boldsymbol{\beta_{T^2}}$ and $\boldsymbol{\beta_{T^2P^2}}$). Table B-3 and B-4 present the estimated coefficients of two conservation mappings—one for conservation among single family households and another for conservation among multiple family complexes.

Table B-3: Single Family Conservation per Household—Estimated Conservation Mapping

Variable Name	Coefficient	Standard Error	t-Statistic
Low Flow Showerhead retrofits	5.471	0.745	7.255
ULF toilet retrofits	8.554	1.772	4.827
ULF toilet retrofits * number of people in household	5.988	0.812	7.372
ULF toilet retrofits * number of people in household (squared)	-0.257	0.044	-5.81
(Indicator = 1) if household located in Santa Monica	33.484	2.501	13.386
(Indicator = 1) if household located in West Los Angeles or San Pedro	11.98	2.057	5.823
(Indicator = 1) if household located in the S.F. Valley	9.832	1.655	5.942
Indicator (= 1) if meter was read in May or June 1990	32.856	2.785	11.797
Indicator (= 1) if meter was read in July or August 1990	64.704	3.166	20.436
Indicator (= 1) if meter was read in September or October 1990	46.923	3.141	14.938
Indicator (= 1) if meter was read in November or December 1990	13.238	2.986	4.433
Indicator (= 1) if meter was read in January or February 1991	-1.294	2.534	-0.511
Indicator (= 1) if meter was read in March or April 1991	35.25	2.415	14.598
Indicator (= 1) if meter was read in May or June 1991	93.344	2.667	34.995
Indicator (= 1) if meter was read in July or August 1991	131.984	3.001	43.979
Indicator (= 1) if meter was read in September or October 1991	125.226	3.246	38.579
Indicator (= 1) if meter was read in November or December 1991	77.689	2.884	26.94
Indicator (= 1) if meter was read in January or February 1992	22.509	2.575	8.741

Variable Name	Coefficient	Standard Error	t-Statistic
Indicator (=1) if meter was read in March or April 1992	33.766	2.449	13.789
Indicator (=1) if meter was read in May or June 1992	58.737	2.79	21.05
Indicator (=1) if meter was read in July or August 1992	71.492	3.997	17.887

Dependent variable : Model Estimated Conservation (gpd per household)
Observations : 38303
R-Square : 0.3962

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Table B-4: Multiple Family Conservation per Unit—Estimated Conservation Mapping

Variable Name	Coefficient	Standard Error	t-Statistic
Low Flow showerhead retrofits per unit	5.178	0.567	9.127
ULF toilet retrofits per unit	6.394	1.557	4.107
Declining effect of ULF toilet retrofits; 0 if retrofits per unit ≤ 1, ULF retrofits per unit (squared) otherwise	-9.483	0.896	-10.579
ULF toilet retrofits per unit * number of persons per unit	17.599	0.721	24.408
ULF toilet retrofits per unit * number of persons per unit (squared)	-0.703	0.075	-9.337
(Indicator =1) if complex located in West Los Angeles or San Pedro	-3.935	0.721	-5.455
(Indicator =1) if complex located in the S.F. Valley	-6.363	0.611	-10.41
Indicator (=1) if meter was read in May or June 1990	14.44	1.133	12.74
Indicator (=1) if meter was read in July or August 1990	17.737	0.993	17.858
Indicator (=1) if meter was read in September or October 1990	16.777	1.016	16.508
Indicator (=1) if meter was read in November of December 1990	9.181	1.039	8.84
Indicator (=1) if meter was read in January or February 1991	7.429	1.012	7.341
Indicator (=1) if meter was read in March or April 1991	19.647	0.957	20.531
Indicator (=1) if meter was read in May or June 1991	33.69	0.928	36.321
Indicator (=1) if meter was read in July or August 1991	45.535	0.959	47.49
Indicator (=1) if meter was read in September or October 1991	41.767	0.99	42.171
Indicator (=1) if meter was read in November or December 1991	41.825	1.056	39.62
Indicator (=1) if meter was read in January or February 1992	32.714	0.987	33.152

Variable Name	Coefficient	Standard Error	t-Statistic
Indicator (=1) if meter was read in March or April 1992	31.007	0.947	32.731
Indicator (=1) if meter was read in May or June 1992	33.443	0.981	34.107
Indicator (=1) if meter was read in July or August 1992	34.871	1.452	24.024

Dependent variable : Model Estimated Conservation (gpd per unit)
Observations : 69807
R-Square : 0.3731

The coefficients have the expected signs and reveal declining marginal returns for toilet retrofits within a home. Furthermore, the estimated mapping strongly rejects the hypothesis of linearity that forms the basis of the mechanical approach—the coefficient $\beta_{T^2P^2}$ is negative and significantly different from zero.

Appendix C: Commercial ULF Toilet Replacement

Analyzing the water savings from ULF toilet replacement in commercial-institutional and industrial sites was more involved for several reasons. Commercial sites[33] differ greatly among themselves. While it is easy to think of a "typical" single family detached residence, there is no "typical" commercial site. This heterogeneity among commercial sites has several implications. Patterns of occupancy and water use differ greatly from site to site. Patterns of toilet use can also differ greatly from site to site; some commercial toilets are thought to be subject to a much greater load. Commercial sites use many different types of restroom toilets (floor vs. wall-mounted, flushometer valve vs. tank toilets, gravity-fed vs. pressurized). Many commercial buildings have multiple stories, which complicates drainage design for the building (due to low drain slopes, bends, varying water pressure, and system effects.) Toilet end-uses form a significant and predictatable share of total water use in a typical residential account. Many commercial sites, however, do not share this characteristic.

Methods

The heterogeneity of commercial sites complicates the analytic task of quantifying conservation. Our treatment of commercial participants takes two steps to handle the variation in water use across types of commercial sites. First, participating accounts are placed into one of 14 types of commercial sites based upon the Standard Industrial Classification (SIC) retained in the LADWP billing system. Unlike the billing systems measurement of the "number of units" for multiple family complexes, no proxy for the level of water use exists for commercial accounts. Second, a stratified random sample of commercial accounts was drawn from the billing system and similarly categoried to form appropriately match control groups. (The randomly drawn account numbers were cross-checked against the rebate tracking database to exclude any participants. Table C-1 presents the

[33] "Commercial" is used to refer to all commercial, industrial, and institutional sites.

categories of commercial use, SIC designations, and sample counts for the participant sample and random control sample.

Table C-1: Types of Commercial Accounts in the Sample

Firm Type	Number of Accounts *(Percent of Sample)*	
	Participants	Random Sample
Construction (SIC>1500 & SIC<1800)	6 *1.9%*	*49* *2.68%*
Wholesale Trade (SIC>5000 & SIC<5200)	14 4.5%	121 6.62%
Public Administration (SIC>9000 & SIC<9999)	18 5.8%	129 7.05%
Hotels and Motels (SIC>7000 & SIC<7100)	15 4.8%	10 0.55%
Restaurants (SIC>5800 & SIC<5900)	23 7.4%	171 9.35%
Finance, Banking, and Real Estate (SIC>6000 & SIC<6800)	45 14.5%	220 12.03%
Misc. Retail (SIC>5200 & SIC<5800) and (SIC>5900 & SIC<6000)	56 18.0%	503 27.50%
Misc. Services and Commercial (SIC>7200 & SIC<7900) and (SIC>8100 & SIC<8200) and (SIC>8300 & SIC<9000)	100 32.15%	603 32.97%
Other	34 10.93%	--
Total	311 100.00%	1829 100.00%

Models of water use per commercial account were estimated for each of the categories in a pre-drought and pre-program period. The forecasts from these models were used as the estimate of "expected" water use per account. The measure of conservation per account was formed by the difference between model estimated "expected" use and actual water use. The estimated conservation among the nonparticipating commercial accounts defines the ongoing conservation in response to the drought. Any additional conservation among participating accounts defines the net program effect.

Estimated Commercial Conservation

The model used to estimate water savings from commercial ULF toilet replacement takes the following form:

$$C = \beta_T \cdot T + \beta_S \cdot S + \alpha_{meter} \cdot MeterSize + \alpha_i + \epsilon_i$$

$$\text{where } i = 1,2,\ldots,6 \ (\textit{bimonthly index}) \qquad (16)$$

$$\text{and} \quad \epsilon_i \sim \mathbf{N}(0, \sigma_i^2)$$

In addition, the estimation procedure weights the above equation by the square root of the number of replaced toilets, using a grouped regression assumptions. Table C-2 presents the estimated model of water savings. The estimated mean savings per toilet, $\boldsymbol{\beta}_T$, is about 73.6 gpd per toilet with an estimated standard error of 1.54 gallons. The 95 percent confidence interval is formed by 1.96 standard errors to either side of the mean, i.e., 73.6 ± 3 gallons per day per toilet. Note that the regression controls for the number of showerheads retrofit, the meter size, and the ongoing conservation in a given time period.

Several cautionary notes should be made. First, savings per toilet estimates varied greatly across different commercial sites. As such, the estimate of mean savings per commercial toilet presented in this report may not extrapolate well to new commercial retrofits in Los Angeles. Extrapolation to other areas outside of Los Angeles would be more tenuous. Second, this study did not have access to indicators of the type of commercial toilet. It would be very interesting to test if flushometer-valve toilets experience higher levels of usage in commercial sites than gravity-feed, tank type toilets. Because flushometer-value ULF toilets are more expensive to purchase and install, higher levels of water savings would be required of commercial replacements in order to achieve the same levels of cost-effectiveness observed in the residential programs. The estimates present in Table C-2, however, do suggest higher overall levels of water savings and conservation potential in the commercial sector. Water managers and planners should retain a healthy sense of skepticism and require additional empirical evidence before confidently extrapolating these savings to other sites.

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Table C-2: Estimated Savings of Commercial ULF Toilet Replacements

Variable Name	Coefficient	Standard Error	t-Statistic
Indicator for the Number of ULF Toilets Replaced	73.583	1.541	47.750
Indicator for the Number of LF Showerheads Replaced	38.393	2.478	15.496
Indicator (=1) for meter size ≤ 1.5 inches	131.399	14.661	8.962
Indicator (=1) for meter size of 2 inches	435.272	15.659	27.797
Indicator (=1) for meter size ≥ 3 inches	65.301	37.775	1.729
Indicator if meter was read in May or June 1990	-9.240	29.449	-0.314
Indicator if meter was read in July or August 1990	-39.589	20.958	-1.889
Indicator if meter was read in September or October 1990	-0.685	21.571	-0.032
Indicator if meter was read in November of December 1990	29.476	22.430	1.314
Indicator if meter was read in January or February 1991	21.292	22.193	0.959
Indicator if meter was read in March or April 1991	125.743	21.193	5.933
Indicator if meter was read in May or June 1991	171.728	20.802	8.255
Indicator if meter was read in July or August 1991	158.338	20.173	7.849
Indicator if meter was read in September or October 1991	120.505	20.551	5.864
Indicator if meter was read in November or December 1991	161.451	21.990	7.342
Indicator if meter was read in January or February 1992	99.682	21.757	4.582
Indicator if meter was read in March or April 1992	93.029	20.510	4.536
Indicator if meter was read in May or June 1992	98.414	20.713	4.751
Indicator if meter was read in July or August 1992	81.185	30.228	2.686

Dependent variable : Model Estimated Conservation (gpd per account)
Observations : 35040
R-Square : 0.2189

Santa Monica Public School Urinal and ULF Toilet Replacement

The City of Santa Monica replaced urinals and toilets in public school bathrooms with high efficiency versions. Due to the lack of any nonparticipating schools, no direct control group could be constructed. Thus, we use a simple one-step regression model to capture the mean effect per device installed. Because the urinals were replaced at the same time as the ULF toilets, we were unable to discern separate mean effects for each device. Though this type of self-reflexive model yields an accurate estimate of the change in water use over time, it does not answer the question of what savings may have occurred in the absence of this program.

Table C-3 provides the regression estimates of Santa Monica public school water use. The mean saving effect per device is about 39.8 gpd with a standard error of about 5 gpd. The large size of the resultant confidence interval, approximately 40 ± 10 gpd, is rather wide. This does speak of the low resolution of this model.

Table C-3: Estimated Savings of Public School ULF Toilet and Urinal Replacements

Variable Name	Coefficient	Standard Error	t-Statistic
Number of ULF toilets or Urinals	-39.842	4.984	-7.994
Indicator (=1) for School Number 1	-261.561	344.058	-0.760
Indicator (=1) for School Number 2	1230.211	483.558	2.544
Indicator (=1) for School Number 3	193.133	392.346	0.492
Indicator (=1) for School Number 4	1360.382	472.092	2.882
Indicator (=1) for School Number 5	-1248.329	395.941	-3.153
Indicator (=1) for School Number 6	2942.604	330.209	8.911
Indicator (=1) for School Number 7	17323.290	1232.325	14.057
Indicator (=1) for School Number 8	8115.445	441.277	18.391
Indicator (=1) for School Number 9	29238.050	1517.145	19.272
Intercept	3054.587	260.119	11.743

Dependent variable : Water use (gpd per account)
Observations : 208
F(10, 219) : 87.99
R-Square : 0.8007

Appendix D: Community Based Organizations

This appendix provides the estimated model of net conservation from the Mothers of East Los Angeles pilot ULF toilet distribution. Prior to the conduct of this analysis, it was widely believed that CBO-run ULF toilet programs would be able to achieve higher levels of conservation for several reasons. First, it was believed that participating households would exhibit both more residents and fewer toilets that the average household in the service area. Second, it was hypothesized that the targeted households might contain a larger share of very old, inefficient, or leaking toilets. The findings of this analysis suggest that there is empirical support for higher levels of per toilet water savings. Further, it appears that the higher level of water savings can be explained by the larger number of persons per household. Specifically, per capita water savings among single family households in East Los Angeles is nearly identical to per capita water savings among single family households in the LADWP service area.

Characteristics of the Sample

The analysis of the MELA-run toilet distribution follows the same methodology used in the ULF rebate program. Table D-1 provides the descriptive statistics of a sample of single family participants that were given an in-person follow-up interview by MELA. The interviews were conducted in the fall of 1993 using a bilingual version of the standard DWP inspection form. There are a number of reasonable questions that can be raised about the data quality of retrospective data, especially concerning sensitive items such as household demographics. By relying on the reputation of this community-based organization to ensure data quality while protecting the privacy of participants, we have confidence in the intrinsic validity of the data. MELA performed the on-site surveys and matched complete surveys against their computer tracking system.

Note that participants in this targeted program were less likely to have cloths washers, pools, and hot tubs. Further, most of the water use could be reasonably believed to occur in indoor water uses; only half of the households reported any irrigation was much less than that reported among all single family households in the service area. More than 80 percent of respondents reported paying their own water bill.

Table D-1: Characteristics of Single Family Households in East Los Angeles

CHARACTERISTICS	EAST LOS ANGELES
Mean number of people per household	4.28
Mean number of toilets per household	1.33
Mean number of ULF toilets replaced per household	1.29
Mean number of showerheads per household	1.33
Mean number of lowflow showerheads per household	1.24
Proportion of households with washing machines	0.81
Proportion of households with lawns	0.51
Proportion of households that reported turf area information	0.80
Mean turf area among reporting households (square feet)	73.
Proportion of households with a sprinkler irrigation system	0.01
Proportion of households with an automatic sprinkler irrigation system	0.00
Proportion of households with a pool	0.01
Proportion of households with a spa or tub	0.00
Proportion of households paying their own water bill	0.86
Mean water use per household (gpd) in estimation period	353

Estimated Net Conservation

Following the methodology used in the impact evaluation of the toilet rebate programs, a model of household water use was estimated in a pre-drought and pre-program period. The statistical model was used to forecast into the program period. The model forecasts were used as estimates of expected water use and the estimate of household conservation was formed by the difference between (model estimated) expected use and actual water use. The conservation among program participants is then compared to the conservation among nonparticipants. For this

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program, we use a purely "self-reflexive" control group--water use of participants prior to the date of their participation in the program.

Figure D-1 provides the graphical description of ongoing conservation (among pre-participants) and net conservation. The estimate of net conservation is formed by subtracting ongoing conservation from the total (gross) conservation of participants. Table D-2 provides the numerical description of the underlying statistical model (an analysis of variance with bimonthly specific error terms.) The mean net participation effect, averaged across the five bimonthly effects, is 58.6 ± 14 gallons per day per household.

Since the reported installation date for low flow showerheads was almost uniformly prior to fall of 1992, very nearly all of the participation effect would be attributed to installation of ULF toilets. The implied per toilet effect is approximately 45 gallons per day per toilet (58.6 gallons per day per household divided by 1.3 replacements per household). The implied per capita effect is approximately 13.7 gallons per day per person (58.6 gallons per day per household divided by 4.28 persons per household).

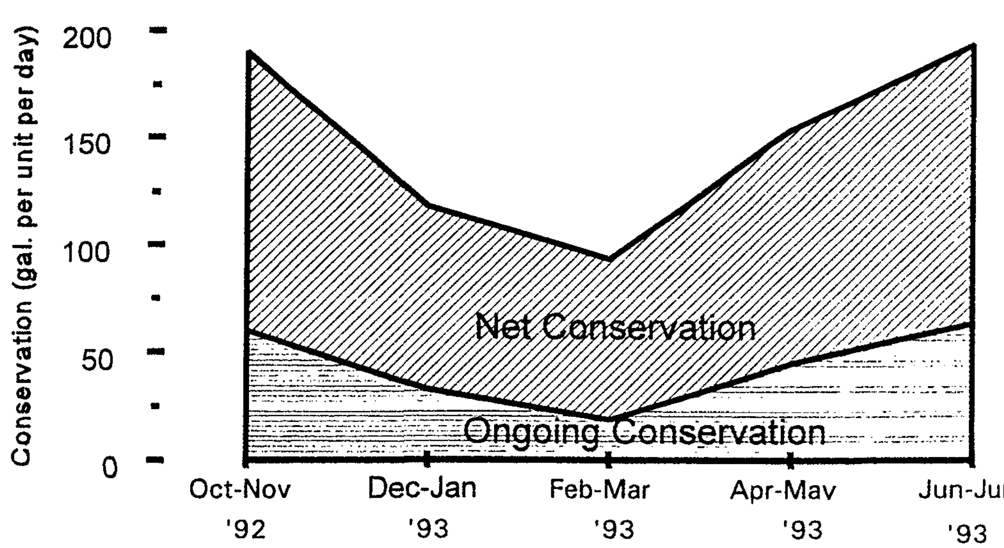

Figure D-1: East Los Angeles: Ongoing Conservation (Preparticipants) vs. Net Conservation (Participants).

Table D-2: East Los Angeles Single Family Conservation per Household

Variable Name	Coefficient	Standard Error	t-Statistic	Count
Indicator (=1) if meter was read in November or December 1992	60.587	9.313	6.506	216
Indicator (=1) if meter was read in January or February 1993	33.608	8.512	3.948	135
Indicator (=1) if meter was read in march or April 1993	19.214	10.292	1.867	104
Indicator (=1) if meter was read in May or June 1993	45.382	11.619	3.906	107
Indicator (=1) if meter was read in July or August 1993	64.074	23.104	2.773	28
Net Participation Effect				
Participant Indicator* (=1) if meter was read in November or December 1992	69.655	25.428	2.739	105
Participant Indicator* (=1) if meter was read in January or February 1993	51.886	13.106	3.959	158
Participant Indicator* (=1) if meter was read in March or April 1993	55.361	13.304	4.161	190
Participant Indicator* (=1) if meter was read in May or June 1993	64.064	14.386	4.453	217
Participant Indicator* (=1) if meter was read in July or August 1993	66.920	24.417	2.7407	294

Dependent variable : Model Estimated Conservation (gpd per household)
Observations : 1271
R-Square : 0.3596